Volume 25 DECEMBER, 1941 Number 12

BULLETIN
of the
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CONTENTS

Mississippian Formations of Sacramento Mountains, New Mexico
By L. R. Laudon and A. L. Bowsher 2107
Experiments with Lights, Shadows, and Contours, and Resulting Shadowgraphic Contour Maps *By Robert F. Imbt* 2161
Deposition of Free Oil by Sediments Settling in Sea Water
By O. A. Poirier and George A. Thiel 2170
Trace-Slip Faults *By R. H. Beckwith* 2181

GEOLOGICAL NOTES

Apache Pool, Caddo County, Oklahoma *By H. H. Arnold, Jr.* 2194

DISCUSSION

Stratigraphic Nomenclature *By H. G. Schenck et al., Hollis D. Hedberg, C. W. Tomlinson, J. E. Eaton, and R. T. White* 2195
Well Logging by Radioactivity *By William L. Russell* 2211

REVIEWS AND NEW PUBLICATIONS

Introduction to Physical Geology, by W. J. Miller
By Herschel L. Driver 2212
Recent Publications 2212

THE ASSOCIATION ROUND TABLE

Membership Applications Approved for Publication 2216
Meetings of Scientific Societies in December 2217
Association Committees 2218
Twenty-Seventh Annual Meeting, Denver, April 21-24, 1942 2220

MEMORIAL

Robert Thomas Hill *By W. E. Wrather* 2221
Baker Hoskins, Jr. *By H. V. Tygrett* 2228
Arthur Albert Wedel *By Ira H. Cram* 2230

AT HOME AND ABROAD

Current News and Personal Items of the Profession 2232

INDEX OF VOLUME 25 (1941) 2235

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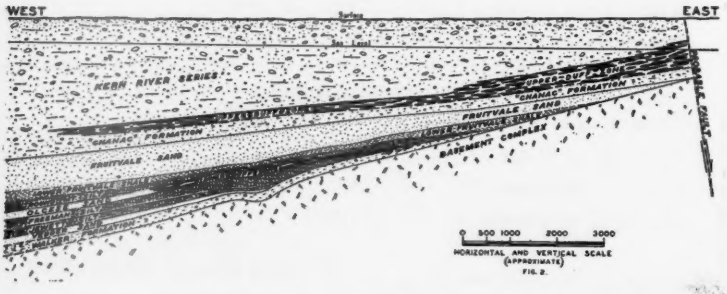

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Seismic Explorations, Inc. xxiii
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Society of Exploration Geophysicists xvii
Spencer Lens Company xix
Sperry-Sun Well Surveying Company v
Tobin Aerial Surveys xxv
Thompson Tool Company, Inc. xxvii
Triangle Blue Print and Supply Company ....
United Geophysical Company ....
Western Geophysical Company xliii

PROFESSIONAL CARDS

California ix
Colorado ix
Illinois ix
Indiana ix
Iowa x
Kansas x
Louisiana x
New York x
Ohio x
Oklahoma xi
Pennsylvania xi
Texas ....xi, xii, xiii
West Virginia xiii
Wyoming xiii

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

Appalachian xvi
Ardmore xv
Dallas xv
East Texas xv
Exploration Geophysicists xvi
Fort Worth xvi
Houston xvi
Illinois xiv
Kansas xiv
Michigan xiv
Mississippi xv
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South Louisiana xiv
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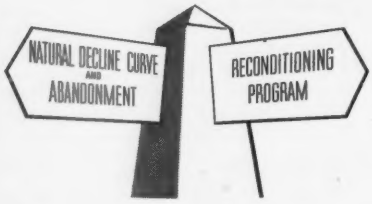

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Volume 25 Number 12

BULLETIN
of the
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DECEMBER, 1941

MISSISSIPPIAN FORMATIONS OF SACRAMENTO MOUNTAINS, NEW MEXICO[1]

L. R. LAUDON[2] AND A. L. BOWSHER[3]
Lawrence, Kansas

ABSTRACT

Formations of Mississippian age are exposed along the west face of the Sacramento Mountains of New Mexico from a short distance north of Alamogordo southward to the vicinity of Grapevine Canyon. Detailed sections have been measured and the faunas collected throughout the entire area of exposure. The name Caballero is proposed for the gray, nodular, marly limestone formation of Kinderhook age lying at the base of the Mississippian section. The Caballero formation has heretofore been considered as a part of the Lake Valley formation. The Lake Valley formation has been divided into three members, Alamogordo at the base, followed by Arcente, and capped by Dona Ana. The fauna of the Caballero formation is closely related to that of the Chouteau formation of the upper Mississippi Valley region. The Lake Valley formation is entirely of early Osage age. Both Fern Glen and lower Burlington faunas can be recognized. Spectacular, large bioherms characterize the Alamogordo member, making it necessary to subdivide the member into several facies.

INTRODUCTION

A preliminary trip into the type area of the Lake Valley formation at Lake Valley, New Mexico, was made in 1936 to study the fossil crinoids that have long been known to occur abundantly in the area (33). At Lake Valley we found that the crinoids were largely confined to one small zone within the formation. Preliminary work in the San Andres and Sacramento mountains revealed that the sections exposed there were much more extensive than those exposed at Lake Valley. We also discovered that excellently preserved crinoid faunas could be obtained in both the San Andres and Sacramento mountains in stratigraphic zones other than the crinoid-bearing beds at Lake Valley. The crinoid faunas collected in areas other than at Lake Valley contain large numbers of new species of crinoids apparently not represented at Lake Valley.

[1] Manuscript received, May 13, 1941.

[2] Associate professor of geology, University of Kansas.

[3] Kansas Geological Survey.

Before the faunas could be accurately located within the exposed section we found it necessary to study the stratigraphy carefully. Since the best exposed and maximum sections are found in the Sacramento Mountains, it is desirable to describe the stratigraphy of this area first.

LOCATION OF THE AREA

The Sacramento Mountains lie in central southern New Mexico. As a continuous range, they begin a few miles north of Tularosa as an

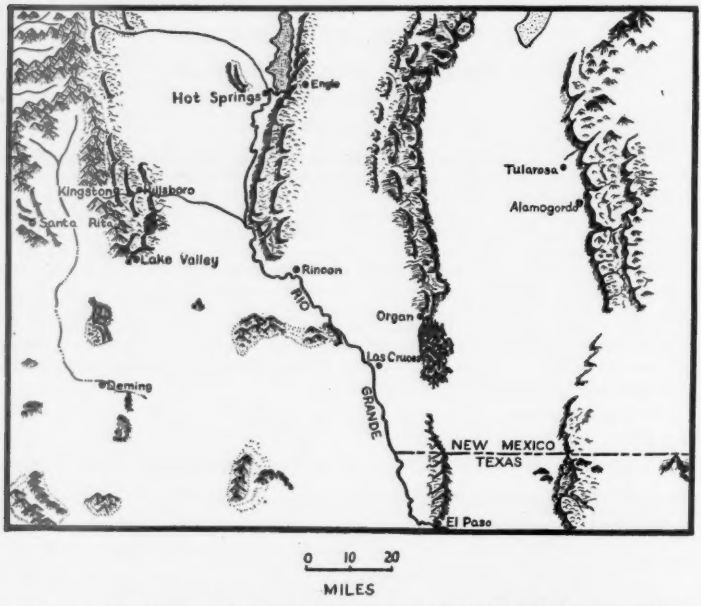

FIG. 1.—Map showing location of Sacramento Mountains. The four ranges here shown from west (left) to east (right) are: Mimbres Mountains, Sierra Caballos, San Andres Mountains, and Sacramento Mountains.

offshoot of the massive igneous block represented by the peak Sierra Blanca. The range slowly diminishes in height toward the south to the vicinity of T. 20 S., R. 11 E. A continuation of the structural trend southward would carry it to the Hueco Mountains of Texas. The west face of the mountains facing the Tularosa Valley is abrupt and imposing. From the crest of the range, the surface slants slowly eastward with a barely perceptible grade.

PREVIOUS WORK

Interest in the rocks exposed at Lake Valley was first manifested with the discovery of the Lake Valley silver deposits. First reference to the fauna of the Lake Valley beds was made by White (39) and later by Miller (28) in 1882. The Lake Valley formation was named by Cope (44) in 1882 at which time its Carboniferous age was first determined. Although Cope did not propose directly that the name Lake Valley formation be used for these strata he did introduce the term Lake Valley as applicable to these beds. Because of this fact we feel that Cope (44) should be given credit for naming the Lake Valley formation and not as suggested by Keyes (19). Silliman (32) also referred to the Carboniferous age of the Lake Valley beds in 1882. On the basis of the crinoid fauna Springer (33) correlated the Lake Valley limestone with the lower Burlington limestone of Iowa. A considerable part of the Lake Valley crinoid fauna was described by Wachsmuth and Springer (38) in 1897. The general stratigraphy of the Lake Valley formation was described by Gordon (10) in 1906 and further outlined in 1907 (11).

The Devonian and Mississippian section of southwestern New Mexico has been subdivided by Keyes (15, 16, 17, 19) and his terms have been in use for some time. Considerable difficulty is encountered, however, in following the application of these terms through the literature.

The name Socorran series was proposed by Keyes (16), in 1906, for the Mississippian limestones of southwestern New Mexico. Later in the same year, however, Keyes (15) introduced the name Berenda for limestones in the Mississippian lying below his Socorran series and above Devonian formations. No derivation of the name nor type section was given. Later Keyes (17) included in his Socorran series as exposed at Lake Valley the Berenda limestone at the base, overlain by the Grande limestone, overlain by the Lake Valley (restricted) limestone, and capped by the Sierra limestone. This is an entirely natural and good subdivision of the Mississippian section as exposed at Lake Valley. Had this terminology not been involved in later confusion it would have been excellently applicable today. The Berenda limestone as exposed at Lake Valley carries an excellent Kinderhook fauna and would be a direct correlative of the Caballero formation as used in this paper. The Grande, Lake Valley, and Sierra limestones of Keyes are definite recognized facies of the Alamogordo member of the Lake Valley formation as used in this paper.

In subsequent papers, however, and in his most recent interpreta-

tion Keyes (19) has considered the Berenda limestone to be of Devonian age. There is a striking lithologic similarity between the nodular marly limestone beds which carry the Ouray limestone fauna and the Kinderhook beds of the Caballero formation. After careful analysis, however, they should never be confused.

In the Lake Valley type section at Apache Hill the Devonian strata carrying the Ouray fauna have been removed by pre-Mississippian erosion. They are excellently exposed, however, only a short distance away on the Wilson ranch. The abrupt nature of the unconformity separating Devonian and Mississippian strata in this area has contributed largely to the confusion.

Keyes apparently has recognized the confusion into which he has fallen. In his recent paper (19) on the "Outlines of New Mexico Geology" he has abandoned the term Berenda entirely and is using the term Ouray limestone. That leaves the basal limestones at Lake Valley without a name or automatically expands his term Grande limestone to include them.

Wilmarth (41) has suppressed all names, except the term Lake Valley, applicable to the Mississippian section of southwestern New Mexico (Socorran, Berenda, Grande, and Sierra). Because of the confused status of these terms we are not using them in the Sacramento Mountains.

A series of sections of the Lake Valley formation was measured by Darton in 1917 (7) along the entire Sacramento Mountain front. Later in 1928 Darton (8) published an areal geology map of the Sacramento Mountains in which he outlined the distribution of the Lake Valley formation essentially as we found it in our work.

Stratigraphy

Formations of Mississippian age crop out in bold escarpments along the western face of the Sacramento Mountains in New Mexico. The west face of the Sacramento Mountains is a fault-line scarp truncating the regional east dip of the formations. The northern end, a short distance north of Alamogordo, is complicated by an anticlinal fold along the west face of the mountains, giving a west to northwest dip to the formations along the mountain front. A few miles north of Alamogordo the formations plunge beneath the overlying Pennsylvanian formations around the nose of the anticlinal structure. On the plunging nose of this anticline the Mississippian formations can be traced around the structure into the mountains where they eventually regain their normal east dip. Farther south the Mississippian formations plunge beneath the valley floor a few miles north of the entrance to Grapevine Canyon.

Throughout the Sacramento Mountains the Mississippian formations are underlain by the Percha shale of Upper Devonian age. Stainbrook (34) recognized two members in the Percha shale in the Sacramento Mountains. The recent work of Stevenson (35) in the area has demonstrated at least three distinct units in the so-called Percha formation, the upper of which is separated from the others by distinct angular unconformity. The contact between the various mem-

SYSTEM	FORMATION	THICKNESS
Triassic	Dockum	300--350
Permian	San Andres Yeso Abo	500-1200 500--600 500--800
Pennsylvanian	Magdalena	800-1400
Mississippian	Lake Valley Caballero	29--420 18---60
Devonian	Percha	0---80
Silurian	Fusselman	100--130
Ordovician	Montoya El Paso Bliss	75--120 200--250 0---50

FIG. 2.—General stratigraphic section as exposed in Sacramento Mountains.

bers of the Percha and the overlying Mississippian formations is distinctly unconformable. It is everywhere marked by an oxidized zone that is filled with phosphatic concretions and locally carries many fish teeth. Local abrupt variations in the thickness of both the basal Mississippian beds and the underlying Percha section are manifestations of this unconformable surface. In the Sacramento Mountains the Mississippian beds have been seen in contact with the two upper members of the Percha formation. As yet we have found no place where pre-Mississippian erosion has cut deeply enough to allow basal Mississippian rocks to come in contact with the basal silts of the Percha formation.

Mississippian rocks are overlain with sharp unconformity by the Pennsylvanian strata. Pre-Pennsylvanian erosion cuts deeply into the

Mississippian surface so that Pennsylvanian strata may be seen in contact with all parts of the Mississippian section from the middle of the Alamogordo member to the top of the Dona Ana member. Various members of the Pennsylvanian section are found in contact with the Mississippian beds. In Marble Canyon immediately above the quarry a thick reworked white chert bed marks the base of the Pennsylvanian. A very short distance away in a tributary valley white quartz sandstone is in contact with the Mississippian beds. At the head of the same tributary normal cherty black Pennsylvanian limestone is in contact with the Mississippian limestone. The relief on the Mississippian surface here is nearly 75 feet within a distance of a few hundred feet.

Mississippian rocks as exposed in the Sacramento Mountains fall within two of the standard Mississippian rock groups. The basal gray nodular limestone beds carry a Kinderhook fauna and the Lake Valley formation carries a fauna of early Osage age.

The terms Kinderhook (27) and Osage (40) are retained as valid, desirable, and distinctly usable units in the standard classification of Mississippian rocks.

The base of the Kinderhook group has long been a subject of controversy by geologists. Branson (2) places the Grassy Creek shale, Saverton shale, and overlying Louisiana limestone in the Devonian on the basis of their fish and conodont faunas. Keyes (18) goes one step further and places the base of the Mississippian at the base of the Chouteau limestone. He does away entirely with the term Kinderhook by placing the Chouteau in what is commonly recognized as the Osage group, although he himself does not recognize the term Osage.

We are still of the opinion that the base of the Kinderhook group should be placed at the base of the black shales commonly designated as Chattanooga. We continue to place it here for the following reasons. The Chattanooga shale is widely divergent from the shale in the normal late Devonian sedimentary basins. It was deposited in the same basins which later received Mississippian sediments. It overlaps with sharp disconformity onto rocks of almost all earlier ages.

We do not object seriously to the assignment of Devonian age to the Chattanooga black shales and to the Louisiana limestone. Regardless of whether they are classified as Devonian or Mississippian the history involved remains the same. The Devonian orogenic movements in the Appalachian area uplifted the eastern part of the continent, causing these inland seas to transgress far and wide beyond the normal Devonian basins.

The upper boundary of the Kinderhook group is subject to some

debate. Keyes (18) discards the term Kinderhook entirely and places the Chouteau formation in the Osage group. Branson (2) correlates the Chouteau limestone with the Fern Glen formation, thereby placing it in the Osage group. Very strong evidence can be advanced conflicting with both contentions.

Practically all workers in the field of Mississippian stratigraphy are unanimous in the recognition of the Chouteau formation in Iowa. The Hampton formation of Laudon (22) can be seen in contact with the rocks designated Chouteau in southeastern Iowa. The Hampton formation is unconformably overlain by the Gilmore City formation and the unconformable contact is exposed near Alden, Iowa. All three formations can be traced easily in the subsurface of western Iowa. There the gray to white oölitic limestone of the Gilmore City formation is overlapped by the green marly limestones of the St. Joe formation which in turn are overlain by the cherty limestones of the Burlington and Keokuk formations. Gilmore City limestone was recognized in this same stratigraphic position in the subsurface in the Forest City basin by McQueen (26). Lee (25) has reported the Gilmore City limestone as lying below typical Osage beds both in northeastern and in western Kansas. It is therefore difficult to correlate the Chouteau limestone with the Fern Glen when it can be seen to lie far below it stratigraphically.

The Gilmore City crinoid fauna is largely duplicated in the basal dark cherty limestone ledges of the Madison formation in Montana. Here it is mixed with normal Kinderhook forms such as *Paryphorhynchus elongatum*, *Productina sampsoni*, and *Shumardella obsolens*.

When Osage and Kinderhook faunas are finally untangled from published lists they will be found to be almost entirely different as far as species are concerned. Ancestors of the specialized Osage forms naturally occur in the Kinderhook.

The Osage beds carry a very distinctive fauna. It is characterized throughout by its greatly diversified crinoid fauna and large ponderous brachiopods. Such forms as *Spirifer rowleyi*, *S. grimesi*, *S. logani*, and *Cliothyridina obmaxima* appear in the lowest beds. We consider such highly specialized forms as *Eutrochocrinus christyi*, *Uperocrinus pyriformis*, various species of *Agaricocrinus*, and *Dorycrinus*, *Amphoracrinus divergens*, and *Physetocrinus lobatus* as widely separated from Kinderhook species so far as stage of evolution is concerned. These types, however, range through the entire Osage.

A comparison of the crinoid faunas of the LeGrand and Gilmore City beds with the Osage crinoids shows an almost complete specific dissimilarity. *Cactocrinus proboscidialis*, the index lower Burlington

fossil as listed by Keyes (18) to aid his correlation of the basal Hampton beds at LeGrand with those of the Burlington, is not found in either the LeGrand or Gilmore City faunas. Nor do any species of *Cactocrinus* that closely resemble *Cactocrinus proboscidialis* occur in the faunas.

Beds of Osage age can be demonstrated to overlap widely on formations of various ages. This profound erosional break is apparent in all areas from the Appalachian slopes to western United States. This erosional break, coupled with the almost complete evolutionary faunal break, militates against discarding the term Kinderhook.

Sacramento Mountain Area

Heretofore all Mississippian rocks exposed in the Sacramento Mountains have been referred to the Lake Valley formation. Since rocks of both Kinderhook and Osage age appear in the section, it seems best to divide them into two formations.

The basal gray, nodular, shaly limestone beds are separated from the overlying Lake Valley formation by a disconformity and carry a fauna closely related to that of the Chouteau formation, of Kinderhook age, in the Upper Mississippi Valley region. Accordingly we are proposing the name "Caballero" for this formation. It is named for Caballero Canyon, the main tributary of Alamo Canyon, where the formation is excellently exposed. The type section is located in the upper end of Deadman Canyon in the south center of Section 3, T. 17 S., R. 10 E. This area has been chosen for the type section because it is possible to see the entire Mississippian section excellently exposed here. Accordingly the type sections of all members were purposely located in this same area.

The restricted term Lake Valley is retained for the remaining portion of the Mississippian section. Topographically the Lake Valley formation divides itself naturally into three members. The basal member crops out in bold escarpments made of resistant limestone. The middle member consists of relatively soft siltstone which weathers to rubbly slopes forming a retreating portion of the mountain front. The upper member, like the basal member, consists of bold escarpments of cherty crinoidal limestone.

We are proposing the name "Alamogordo" for the basal of the three members. It consists normally of hard resistant cliff-forming limestone beds. Throughout much of the Sacramento Mountain area this normal resistant escarpment is complicated by two variations. The basal portion is in many places soft and silty due to the presence of reworked Caballero sediments and the upper portion is complicated by the

presence of large massive bioherm structures with their accompanying offshore facies. The normal development of the Alamogordo member contains a thin soft siltstone facies overlain by an almost vertical cliff of hard, black, resistant, very cherty limestone, followed by a thin soft marly zone, and capped with hard gray crinoidal limestone. Where a

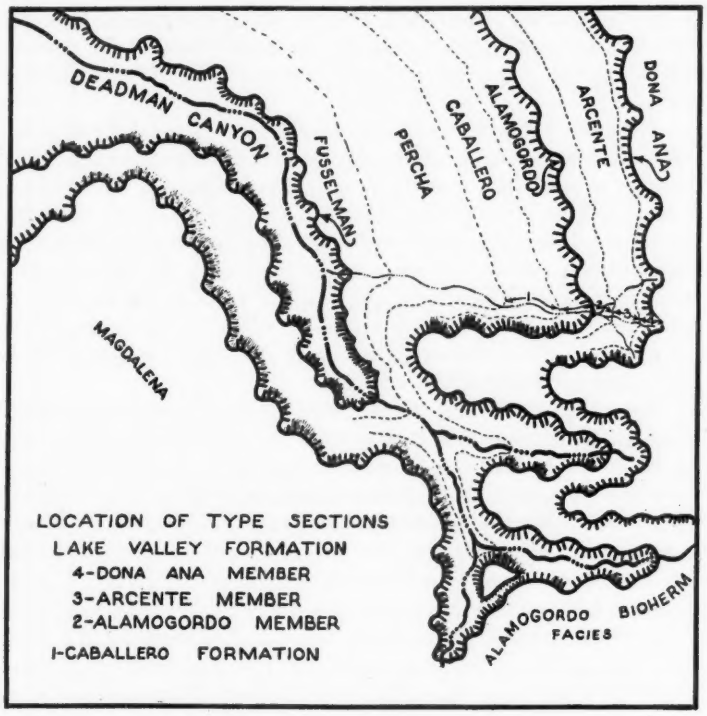

FIG. 3.—Detailed map of Deadman Canyon area showing exact location of type sections. Width of area shown, approximately ¼ mile.

bioherm is developed within the member the topographic expression is dependent on the location of the section with respect to the central mass of the bioherm. The bioherm facies itself forms a huge cliff of almost amorphous black limestone. In the lagoonal area between the bioherm facies the Alamogordo member is commonly broken into three parts topographically. It carries a basal hard, black cherty limestone facies, making a vertical scarp, a medial soft blue-green shaly marl facies, making a retreating portion of cliff, and an upper gray

crinoidal limestone facies, making another vertical cliff. Many variations of this succession can be seen in the intervening areas between the bioherm facies and the lagoonal area. In all places, however, the Alamogordo member stands out distinctly as a cliff-forming portion of the section in distinction from both overlying and underlying beds.

The type section is located at the upper end of Deadman Canyon in the south center of Section 3, T. 17 S., R. 10 E. Complete bioherm structure with accompanying facies can be seen within the Alamogordo member in the three tributaries at the head end of Deadman Canyon.

The name "Arcente" is proposed for the soft, gray, shaly siltstone part of the section lying above the Alamogordo limestone beds. The member is named for Arcente Canyon which traverses the northern end of the main anticlinal structure, in which the Lake Valley beds are well exposed, northeast of Alamogordo. The type section is located in the same area in the south center of Section 3, T. 17 S., R. 10 E. The Arcente member thins abruptly against the main central structure of an Alamogordo bioherm in this area. In order to see the maximum Arcente section it is necessary to go north along the east wall of Deadman Canyon toward Alamo Canyon.

The name "Dona Ana" is proposed for the upper member of the Lake Valley formation. It is named for Dona Ana County in southwestern New Mexico. Topographically the Dona Ana member forms bold projecting cliffs above the soft siltstones of the Arcente member. It consists normally of gray, cherty, crinoidal limestone which locally carries small bioherm structures. The type section is located at the head end of Deadman Canyon in the south center of Section 3, T. 17 S., R. 10 E. It overlies the Arcente and consequently has been removed by pre-Pennsylvanian erosion from the same area immediately above the large bioherm at the head of the canyon. It is necessary to go north along the east wall of Deadman Canyon toward Alamo Canyon to see the member. It is best exposed immediately above the maximum section of the Arcente member.

Text figures 4, 5, 6, 7, and 8 represent a detailed measurement of the type sections of the Mississippian formations of the Sacramento Mountains in Deadman Canyon, Section 3, T. 17 S., R. 10 E.

CABALLERO FORMATION

Lithology.—The Caballero formation has a distinctive, easily recognizable lithology throughout the entire Sacramento Mountain area. It consists of soft, gray, silty limestone beds that weather to rounded, nodular, rubbly chunks on fresh exposures. The light dove-

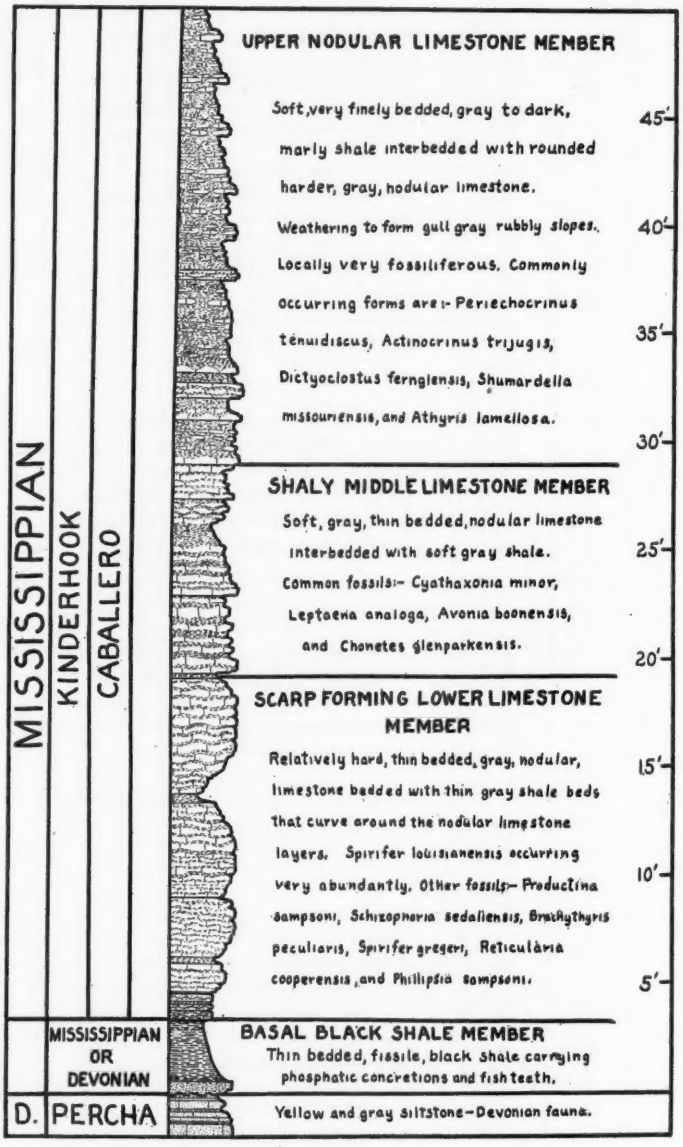
MISSISSIPPIAN
KINDERHOOK
CABALLERO
UPPER NODULAR LIMESTONE MEMBER
Soft, very finely bedded, gray to dark, marly shale interbedded with rounded harder, gray, nodular limestone. Weathering to form gull gray rubbly slopes. Locally very fossiliferous. Commonly occurring forms are:- Periechocrinus tenuidiscus, Actinocrinus trijugis, Dictyoclostus ferngiensis, Shumardella missouriensis, and Athyris lamellosa.
45'
40'
35'
30'
SHALY MIDDLE LIMESTONE MEMBER
Soft, gray, thin bedded, nodular limestone interbedded with soft gray shale. Common fossils:- Cyathaxonia minor, Leptaena analoga, Avonia boonensis, and Chonetes glenparkensis.
25'
20'
SCARP FORMING LOWER LIMESTONE MEMBER
Relatively hard, thin bedded, gray, nodular, limestone bedded with thin gray shale beds that curve around the nodular limestone layers. Spirifer louisianensis occurring very abundantly. Other fossils- Productina sampsoni, Schizophoria sedaliensis, Brachythyris peculiaris, Spirifer gregori, Reticularia cooperensis, and Phillipsia sampsoni.
15'
10'
5'
MISSISSIPPIAN OR DEVONIAN
BASAL BLACK SHALE MEMBER
Thin bedded, fissile, black shale carrying phosphatic concretions and fish teeth.
D.
PERCHA
Yellow and gray siltstone-Devonian fauna.

FIG. 4.—Type section of Caballero formation in Deadman Canyon, Sec. 3, T. 17 S., R. 10 E.

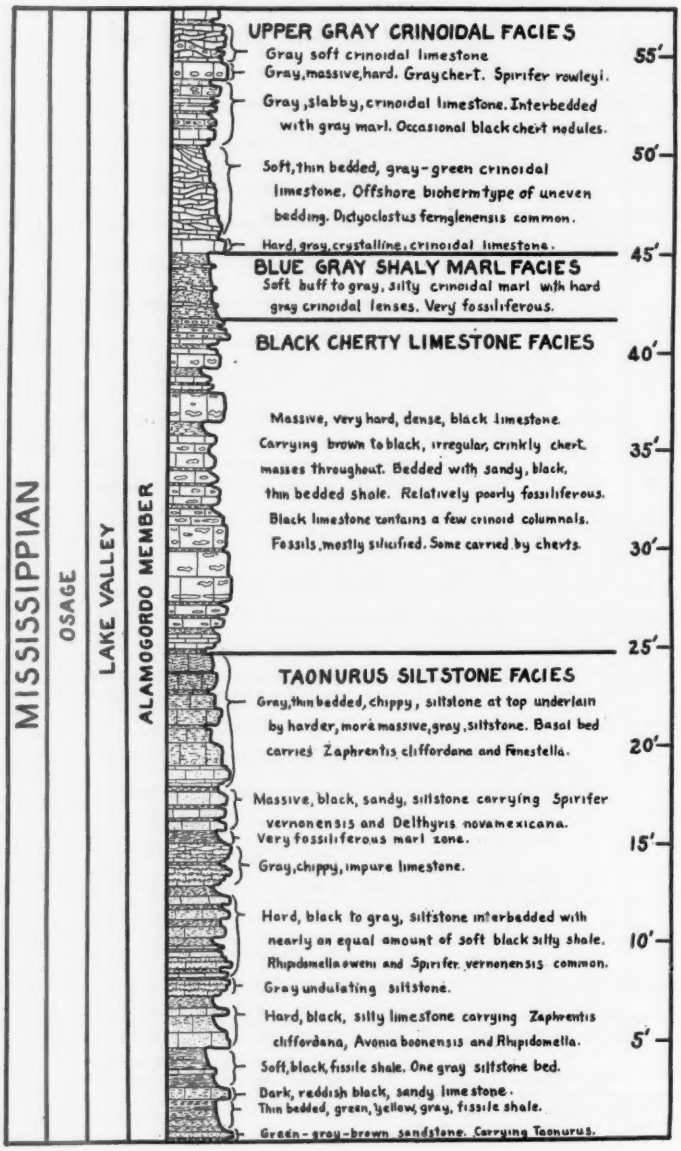
MISSISSIPPIAN
OSAGE
LAKE VALLEY
ALAMOGORDO MEMBER
UPPER GRAY CRINOIDAL FACIES
Gray soft crinoidal limestone
Gray, massive, hard. Gray chert. Spirifer rowleyi.
Gray, slabby, crinoidal limestone. Interbedded with gray marl. Occasional black chert nodules.
Soft, thin bedded, gray-green crinoidal limestone. Offshore biohermtype of uneven bedding. Dictyoclostus ferrylenensis common.
Hard, gray, crystalline, crinoidal limestone.
BLUE GRAY SHALY MARL FACIES
Soft buff to gray, silty crinoidal marl with hard gray crinoidal lenses. Very fossiliferous.
BLACK CHERTY LIMESTONE FACIES
Massive, very hard, dense, black limestone. Carrying brown to black, irregular, crinkly chert masses throughout. Bedded with sandy, black, thin bedded shale. Relatively poorly fossiliferous. Black limestone contains a few crinoid columnals. Fossils, mostly silicified. Some carried by cherts.
TAONURUS SILTSTONE FACIES
Gray, thin bedded, chippy, siltstone at top underlain by harder, more massive, gray, siltstone. Basal bed carries Zaphrentis cliffordana and Fenestella.
Massive, black, sandy, siltstone carrying Spirifer vernonensis and Delthyris novamexicana. Very fossiliferous marl zone.
Gray, chippy, impure limestone.
Hard, black to gray, siltstone interbedded with nearly an equal amount of soft black silty shale. Rhipidomella oweni and Spirifer vernonensis common.
Gray undulating siltstone.
Hard, black, silty limestone carrying Zaphrentis cliffordana, Avonia boonensis and Rhipidomella.
Soft, black, fissile shale. One gray siltstone bed.
Dark, reddish black, sandy limestone.
Thin bedded, green, yellow, gray, fissile shale.
Green-gray-brown sandstone. Carrying Taonurus.
55'
50'
45'
40'
35'
30'
25'
20'
15'
10'
5'

FIG. 5.—Type section of lower portion of Alamogordo member of Lake Valley formation in Deadman Canyon, Sec. 3, T. 17 S., R. 10 E.

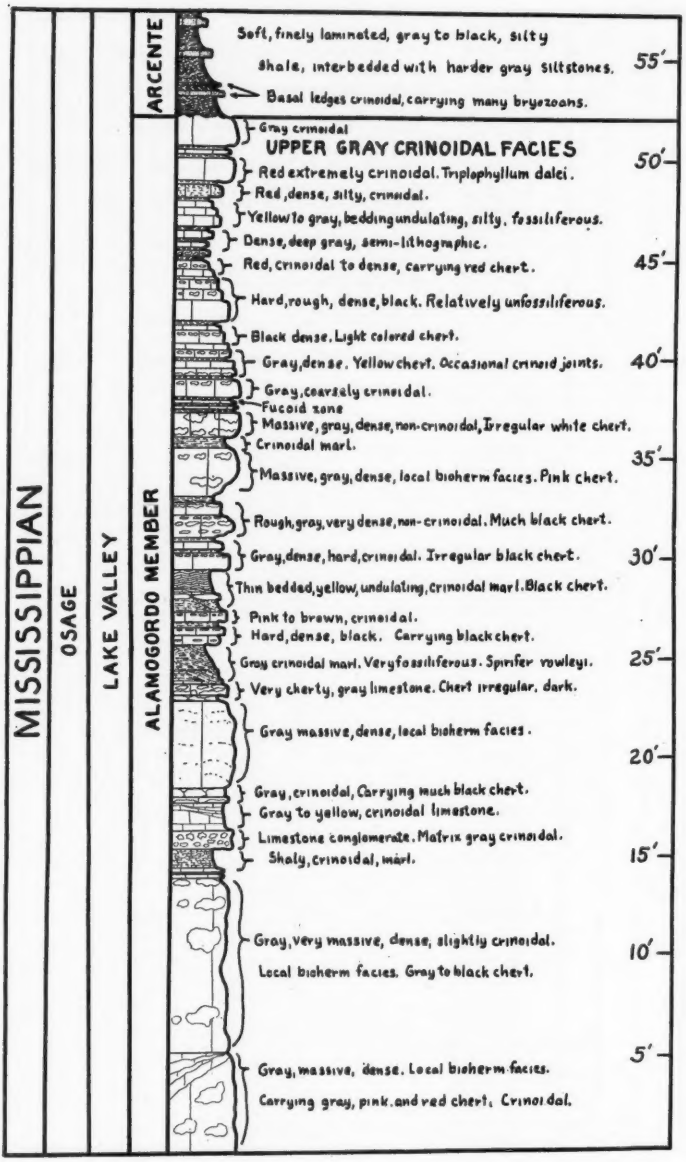
MISSISSIPPIAN
OSAGE
LAKE VALLEY
ALAMOGORDO MEMBER
ARCENTE
Soft, finely laminated, gray to black, silty
shale, interbedded with harder gray siltstones.
55'
Basal ledges crinoidal, carrying many bryozoans.
Gray crinoidal
UPPER GRAY CRINOIDAL FACIES
50'
Red extremely crinoidal. Triplophyllum dalei.
Red, dense, silty, crinoidal.
Yellow to gray, bedding undulating, silty, fossiliferous.
Dense, deep gray, semi-lithographic.
Red, crinoidal to dense, carrying red chert.
45'
Hard, rough, dense, black. Relatively unfossiliferous.
Black dense. Light colored chert.
Gray, dense. Yellow chert. Occasional crinoid joints.
40'
Gray, coarsely crinoidal.
Fucoid zone
Massive, gray, dense, non-crinoidal, Irregular white chert.
Crinoidal marl.
35'
Massive, gray, dense, local bioherm facies. Pink chert.
Rough, gray, very dense, non-crinoidal. Much black chert.
Gray, dense, hard, crinoidal. Irregular black chert.
30'
Thin bedded, yellow, undulating, crinoidal marl. Black chert.
Pink to brown, crinoidal.
Hard, dense, black. Carrying black chert.
Gray crinoidal marl. Very fossiliferous. Spirifer rowleyi.
25'
Very cherty, gray limestone. Chert irregular, dark.
Gray massive, dense, local bioherm facies.
20'
Gray, crinoidal, Carrying much black chert.
Gray to yellow, crinoidal limestone.
Limestone conglomerate. Matrix gray crinoidal.
Shaly, crinoidal, marl.
15'
Gray, very massive, dense, slightly crinoidal.
10'
Local bioherm facies. Gray to black chert.
5'
Gray, massive, dense. Local bioherm facies.
Carrying gray, pink and red chert. Crinoidal.

FIG. 6.—Type section of upper portion of Alamogordo member in Deadman Canyon, Sec. 3, T. 17 S., R. 10 E.

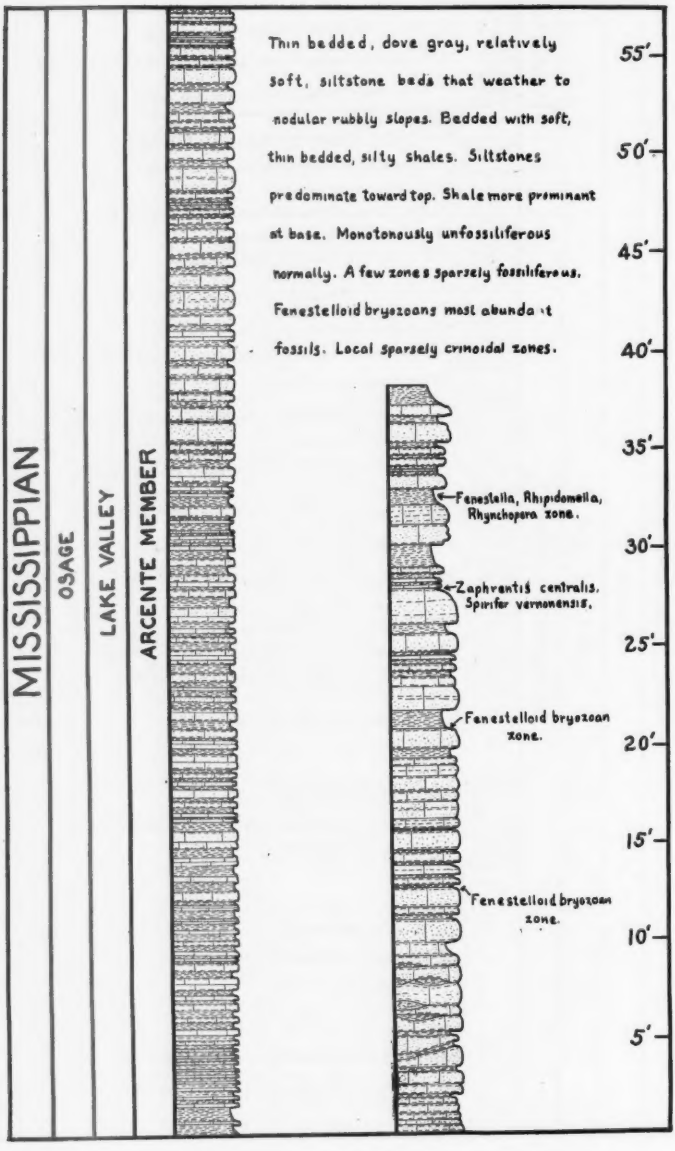

FIG. 7.—Type section of Arcente member of Lake Valley formation in Deadman Canyon, Sec. 3, T. 17 S., R. 10 E.

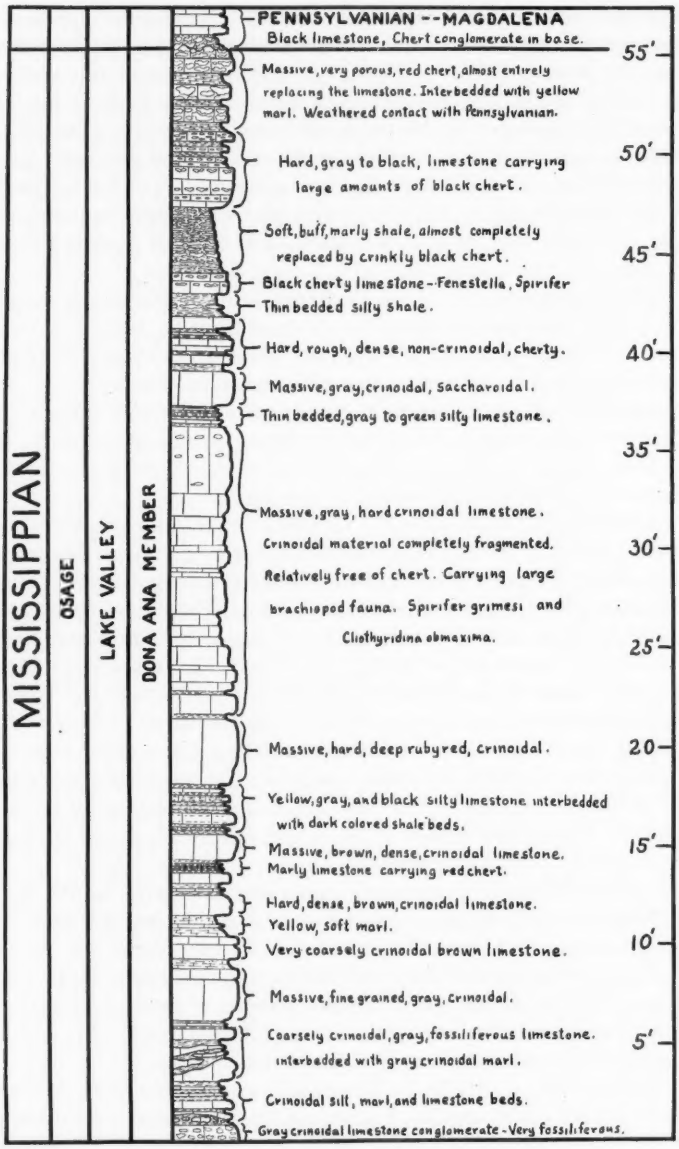
MISSISSIPPIAN
OSAGE
LAKE VALLEY
DONA ANA MEMBER
PENNSYLVANIAN --MAGDALENA
Black limestone, Chert conglomerate in base.
55'
Massive, very porous, red chert, almost entirely replacing the limestone. Interbedded with yellow marl. Weathered contact with Pennsylvanian.
Hard, gray to black, limestone carrying large amounts of black chert.
50'
Soft, buff, marly shale, almost completely replaced by crinkly black chert.
45'
Black cherty limestone--Fenestella, Spirifer
Thin bedded silty shale.
Hard, rough, dense, non-crinoidal, cherty.
40'
Massive, gray, crinoidal, saccharoidal.
Thin bedded, gray to green silty limestone.
35'
Massive, gray, hard crinoidal limestone.
Crinoidal material completely fragmented.
30'
Relatively free of chert. Carrying large brachiopod fauna. Spirifer grimesi and Cliothyridina obmaxima.
25'
Massive, hard, deep ruby red, crinoidal.
20
Yellow, gray, and black silty limestone interbedded with dark colored shale beds.
Massive, brown, dense, crinoidal limestone.
15'
Marly limestone carrying red chert.
Hard, dense, brown, crinoidal limestone.
Yellow, soft marl.
Very coarsely crinoidal brown limestone.
10'
Massive, fine grained, gray, crinoidal.
Coarsely crinoidal, gray, fossiliferous limestone.
5'
interbedded with gray crinoidal marl.
Crinoidal sill, marl, and limestone beds.
Gray crinoidal limestone conglomerate - Very fossiliferous.

FIG. 8.—Type section of Dona Ana member of Lake Valley formation in Deadman Canyon, Sec. 3, T. 17 S., R. 10 E.

gray color of weathered exposures is in itself diagnostic. It appears to be very unevenly bedded due to the nodular nature of the limestone beds. The interbedded soft gray shales curve around the nodular limestone lumps. The soft nature of the formation tends to make a receding component in the topographic expression of the mountain face. In exposures, however, the nodular limestone beds stand out from the interbedded soft shales. The upper portion of the section is everywhere distinctly more shaly and the basal ledges are in many places hard enough to make a small local cliff. Little chert is present in the Caballero formation.

Thickness.—The maximum thickness of the formation is developed in the area between Mule and San Andreas canyons. In both of these canyons it measures a little more than 60 feet in thickness. Although well developed in the northern area in Alamo and Marble canyons it is commonly about 40 feet thick. It appears to thin slightly toward the south. In Dog Canyon it is 28 feet thick and in its southernmost area it is one of the most conspicuous portions of the Mississippian section because the Lake Valley formation is thin in this area.

Stratigraphic relations.—The Caballero formation is underlain unconformably by various members of the Percha formation. The variation in the thickness of the Caballero formation is due mostly to pre-Mississippian erosion on the Percha surface. The top of the Percha throughout most of the area is represented by a thin, black, fissile shale layer. In general its lithology is not unlike that of the black Chattanooga shales of the Mississippi Valley region. Since several similar black shales occur down some distance in the upper portion of the Percha formation we have included this top black shale with the Percha. This black shale carries spores and may eventually be classed as Mississippian. Where the Caballero formation rests on this black shale it is everywhere marked by a layer filled with phosphatic concretions and some fish teeth.

The Caballero formation is overlain unconformably by the basal silty facies of the Alamogordo member of the Lake Valley formation. The overlying *Taonurus* siltstone is soft and consequently it is difficult to separate the formations. The soft nature and gray color of the overlying siltstones is due mainly to the presence of reworked Caballero sediments. There is, however, a distinct break in lithology and in fauna at the top of the Caballero formation.

The details of Percha stratigraphy have not been worked out in the Sacramento Mountains. Stainbrook (34) recognized two members of the Percha shale in Gordon Canyon. The recent work of Stevenson (35) in the area has definitely distinguished three members in the

Sacramento Mountains, the upper of which is sharply unconformable on the underlying beds. In his work Stevenson has not found the typical Ouray limestone (20) fauna in any of the three members. It appears that the beds carrying the Ouray limestone fauna in the Lake Valley area are stratigraphically younger than any part of the Percha formation as exposed in the Sacramento Mountains. We have observed the Caballero formation in contact with the two upper members of the Percha formation. Pre-Mississippian erosion apparently has not cut deep enough to allow the Caballero formation to come down in contact with the lower silts of the Percha formation.

Paleontology.—The Caballero formation is fossiliferous throughout the entire Sacramento Mountain region. On most exposures it is richly fossiliferous. Because the formation consists of soft marly limestone, most of the fossils are excellently preserved. No attempt has been made in this paper to establish faunal zones within the formation although we recognize that certain species range only through limited portions.

Fifty-six species of invertebrates have been identified from the Caballero formation in the Sacramento Mountain area. In addition to these we have a large number of forms that are new or represent varieties of described species. The fauna is predominantly Kinderhook in aspect. Thirty-one species can be considered as typically Kinderhook and nineteen as Osage. Six occur commonly in both Kinderhook and Osage.

The presence of such typical Osage species as *Zaphrentis cliffordana, Monilopora crassa, Palaecis depressus, Dictyoclostus fernglenensis, Ptychospira sexplicata, Brachythyris suborbicularis, Cliothyridina prouti,* and *Athyris lamellosa* suggests that the beds should be classed as Osage or at least very late Kinderhook. It is possible that the Caballero formation represents one of the earliest parts of the Osage sea and the numerous Kinderhook forms are survivors into early Osage times. Because of the great predominance of Kinderhook species we are classifying the Cabellero formation as Kinderhook although we do recognize the possibility of its early Osage age.

The fauna of the Caballero formation is most like that of the Chouteau formation of the Upper Mississippi Valley. Keyes (19) long ago recognized the Chouteau fauna in the basal beds at Lake Valley. The abundant presence of such forms as *Schellwienella chouteauensis, Dictyoclostus calhounensis, Productina sampsoni, Avonia boonensis, Dictyoclostus chouteauensis, Schizophoria poststriatula, Spirifer gregeri, Reticularia cooperensis,* and *Phillipsia sampsoni* indicate very close relationships with the Choteau formation. We are not making a posi-

Text Figure No. 9

FAUNA OF THE CABALLERO FORMATION

	Localities in the Sacramento Mts.						
	1	2	3	4	5	6	7	8
ANTHOZOA								
Cyathaxonia minor			x					
Hadrophyllum romingeri	x							
Zaphrentis cliffordana	x		x	x	x	x	x	
Amplexus rugosus				x				
Palaecis depressus	x			x		x		
Monilopora crassa	x							
CRINOIDEA								
Periechocrinus tenuidiscus				x				
Actinocrinus trijugis				x				
Platycrinus springeri	x							
Platycrinus absentivus				x				
Symbathocrinus wachsmuthi								
BRACHIOPODA								
Lingula gorbyi		x						
Orbiculoidea sampsoni		x						
Leptaena analoga	x	x	x	x	x			
Schuchertella fernglenensis				x				
Schuchertella lens				x				
Schellwienella chouteauensis				x				
Streptorhynchus tenuicostatum				x				
Chonetes glenparkensis	x		x	x	x	x	x	
Productina sampsoni	x	x	x	x				
Echinoconchus chouteauensis			x					
Dictyoclostus fernglenensis			x					
Dictyoclostus chouteauensis	x			x	x			
Dictyoclostus calhounensis	x	x	x	x				
Avonia laevicula			x					
Avonia concentrica			x					
Avonia boonensis	x	x		x				x
Rhipidomella missouriensis	x	x	x	x	x		x	
Schizophoria sedaliensis				x				
Schizophoria poststriatula	x		x					
Camarotoechia tuta				x				
Shumardella missouriensis	x	x	x					
Shumardella obsolens	x	x	x	x	x	x		
Cyrtina burlingtonensis		x	x				x	x
Delthyris novamexicana			x					
Spirifer louisianensis	x	x	x	x	x			x
Spirifer gregeri	x		x	x		x	x	x
Spirifer vantuyli			x					
Spiriferina solidirostris	x		x		x	x	x	x
Brachythyris suborbicularis			x			x		
Brachythyris peculiaris			x	x				x
Ambocoelia levicula	x	x	x	x				
Reticularia cooperensis	x							
Ptychospira sexplicata				x				
Athyris lamellosa	x		x		x	x	x	x
Cliothyridina glenparkensis			x				x	
Cliothyridina prouti	x		x					
Cliothyridina incrassata	x			x				
Cliothyridina tenuilineata	x			x				
Composita lewisensis	x			x				
PELECYPODA								
Conocardium pulchellum			x					
GASTROPODA								
Platyceras glenparkensis				x				
Platyceras evolutum				x				
Platyceras halitoides				x				
Platyschisma missouriensis				x				
PTEROPODA								
Conularia blairi				x				
TRILOBITA								
Phillipsia sampsoni	x	x	x	x			x	x

FIG. 9.—Fauna of Caballero formation, Sacramento Mountains.

1. Marble Canyon—SE¼ of SE¼, Sec. 22, T. 16 S., R. 10 E.
2. Arcente Canyon—E½ of NE¼, Sec. 20, T. 16 S., R. 11 E.
3. Deadman Canyon—SE¼ of NW¼, Sec. 3, T. 17 S., R. 10 E.
4. Mule Canyon—W½ of NW¼, Sec. 9, T. 17 S., R. 10 E.
5. San Andreas Canyon—W½ of SW¼, Sec. 27, T. 17 S., R. 10 E.
6. Dog Canyon—S½ of NE¼, Sec. 10, T. 18 S., R. 10 E.
7. Escondido Canyon—SE¼, Sec. 27, T. 18 S., R. 10 E.
8. Nigger Ed Canyon—NE¼ of NW¼, Sec. 18, T. 18 S., R. 11. E.

tive correlation because we recognize that these Chouteau forms are widely scattered through Kinderhook formations lying above the Chouteau formation. Both the Hampton and Gilmore City formations of Iowa carry a large percentage of typical Chouteau fossils. We have also observed these same faunal assemblages in the upper part of the Kinderhook beds in the Madison limestone of Montana. Most of the Caballero fauna can be duplicated in the shaly limestone beds of the Madison series on Old Baldy Peak in the Bridger Range north of Bozeman, Montana.

Preliminary work has demonstrated that the Caballero formation is widely distributed over southwestern New Mexico. It is well developed throughout most of the San Andres Range. In the northern part of the range it is missing. It is well developed in the Lake Valley area although the typical nodular character is not present. Shaly beds of Caballero age are found in the Cooks Range and also in the Silver City area.

LAKE VALLEY FORMATION

The Lake Valley formation consists of a variable series of cherty limestones, siltstones, and marls complicated by abrupt lateral changes in facies due to the presence of large bioherm masses at various points within the formation. Without a complete understanding of the bioherms and their lateral facies, the stratigraphy becomes hopelessly confusing. Although the formation appears to be interrupted in many places by large unconformities, we are of the opinion that the beds described under the Lake Valley formation represent essentially one continuous period of deposition. The stage of evolution represented by the faunas within the formation seems to suggest gradual evolution within the early Osage sea.

Lithologically the Lake Valley formation normally is divided naturally into three members. The lower consists of massive cliff-forming cherty limestone, the middle of soft gray siltstone, and the upper of hard, massive, cherty, crinoidal limestone. The lower member is complicated in many places with large bioherm structures which break it up into various definite easily recognizable facies. Because the lagoonal facies of the bioherm structure consists of soft, gray marl the lower member is commonly broken into two definite cliffs. To one unfamiliar with the area this fact leads to considerable confusion in dealing with the stratigraphy.

Alamogordo Member

Lithology.—Where the Alamogordo member is not complicated with bioherm structures it consists normally of four very definite zones. The basal zone consists of soft, gray, thin-bedded, silty lime-

stone beds interbedded with softer, silty, shale beds. The gray color is largely due to the incorporation of considerable amounts of reworked Caballero material in the base of the formation. Throughout the Sacramento Mountain area this basal zone is filled with the imprints of *Taonurus caudigaule* and can be appropriately characterized as the *Taonurus* siltstone zone. Under ordinary circumstances the presence of *Taonurus* means little stratigraphically. However, in the Sacramento Mountains its abundant presence may be used very successfully in determining this stratigraphic zone.

The *Taonurus* siltstone is normally overlain by hard, black, relatively massive, very cherty limestone that is markedly unfossiliferous. It weathers to a very rough jagged surface. This black limestone facies makes a definite scarp on the Lake Valley slope. It invariably overhangs the softer underlying *Taonurus* beds. Locally small crinoidal masses are incorporated within the black limestone facies.

This hard black cherty limestone cliff is normally overlain by a soft blue-gray marl zone. In much of the area in the Sacramento Mountains, outside of the bioherm area in the northern end, this marly facies is poorly developed or even entirely absent. In the San Andres Mountains and in the Lake Valley area it is well developed.

The upper zone of the Alamogordo member normally consists of gray, cherty, crinoidal limestone beds that make conspicuous bold cliffs. These gray limestone beds may, in the absence of the marl facies, rest directly on the hard black limestone beds. In the southern part of the Sacramento Mountains both of the upper facies may be absent.

CRINOIDAL BIOHERM STRUCTURE

Crinoidal bioherms are largely confined to the Alamogordo member of the Lake Valley formation in the Sacramento Mountains but occasionally smaller bioherm masses are found in the upper part of the Lake Valley formation in the Dona Ana member.

Reef-like structures in calcareous sediments have been described from many widely scattered localities. The famous coral bioherms in the Niagaran dolomites of Indiana, Illinois, and Iowa were first described by James Hall (14) in 1862. T. C. Chamberlin (3) later described them in detail. Wiman (42) described reefs similar in structure in the Silurian formations on the island of Gotland, Sweden, in 1897. Grabau (13) in 1903 described reefs of limestone in both Devonian and Silurian formations. In 1927 Cumings and Shrock (5) described the Niagaran reefs of Indiana in detail and proposed the term bioherm for these structures. Cumings (6) later, in his retiring presidential address before the Paleontological Society, summarized the whole problem of

bioherms or reefs. Recently Shrock (31) has made a definite attempt to recognize the various facies as developed in these Niagaran bioherms.

Scattered among the various reports are descriptions of crinoidal bioherms in Carboniferous strata. These descriptions nearly always differ quite markedly from the descriptions of the Silurian coral bioherms. These Carboniferous structures are characterized by their tremendous amounts of fragmental crinoidal material and their decided lack of corals. Small parts of the Niagaran bioherms in Iowa consist almost entirely of crinoidal remains but they are associated with large bioherm masses largely filled with corals. Dupont (9) described knolls of amorphous limestone that graded out into well bedded, exceptionally crinoidal limestone in the Carboniferous of Belgium. Parkinson (30) later, in writing of the famous Coplow knoll region of Clitheroe, England, described similar structures. Wright (43) further described these well known crinoid-bearing knoll structures in 1928. In 1931 Stockdale (36) described crinoidal limestone masses wholly enclosed in the clastic silts of the New Providence formation of Kentucky. Structures closely similar but on a smaller scale were described by Laudon (24) from the St. Joe formation of northeastern Oklahoma.

It is necessary to reconstruct the environment of accumulation of these bioherms before they can be correctly interpreted. Grabau (13), Twenhofel (37), Stockdale (36), and Shrock (31) have made attempts at reconstruction of this environment. They have shown that, in all locations, the bioherm grew contemporaneously with the surrounding sediments and that the bioherm structures grade laterally into the surrounding sediments. New Mexico bioherms furnish evidence suggesting that the main bioherm facies rose considerably above the surrounding sediments.

We recognize the problem of compaction of sediments. It could be possible for the hard bioherm facies to accumulate contemporaneously with the surrounding sediments at approximately the same level. If the surrounding sediments were loosely compacted, weight of overlying sediments might at a later date cause compaction, giving rise to the dips on the side of the bioherm structure.

Considerable evidence can be presented that at least partly refutes this possibility. Beds on the side of the bioherm structure are thin and the same beds can be observed to thicken toward the base of the structure. This condition would be normal on a sloping surface. The overlying basal beds of the Arcente member conform with the sloping bioherm surface. The entire thickening of the Arcente member takes place within the member since the upper beds are also in

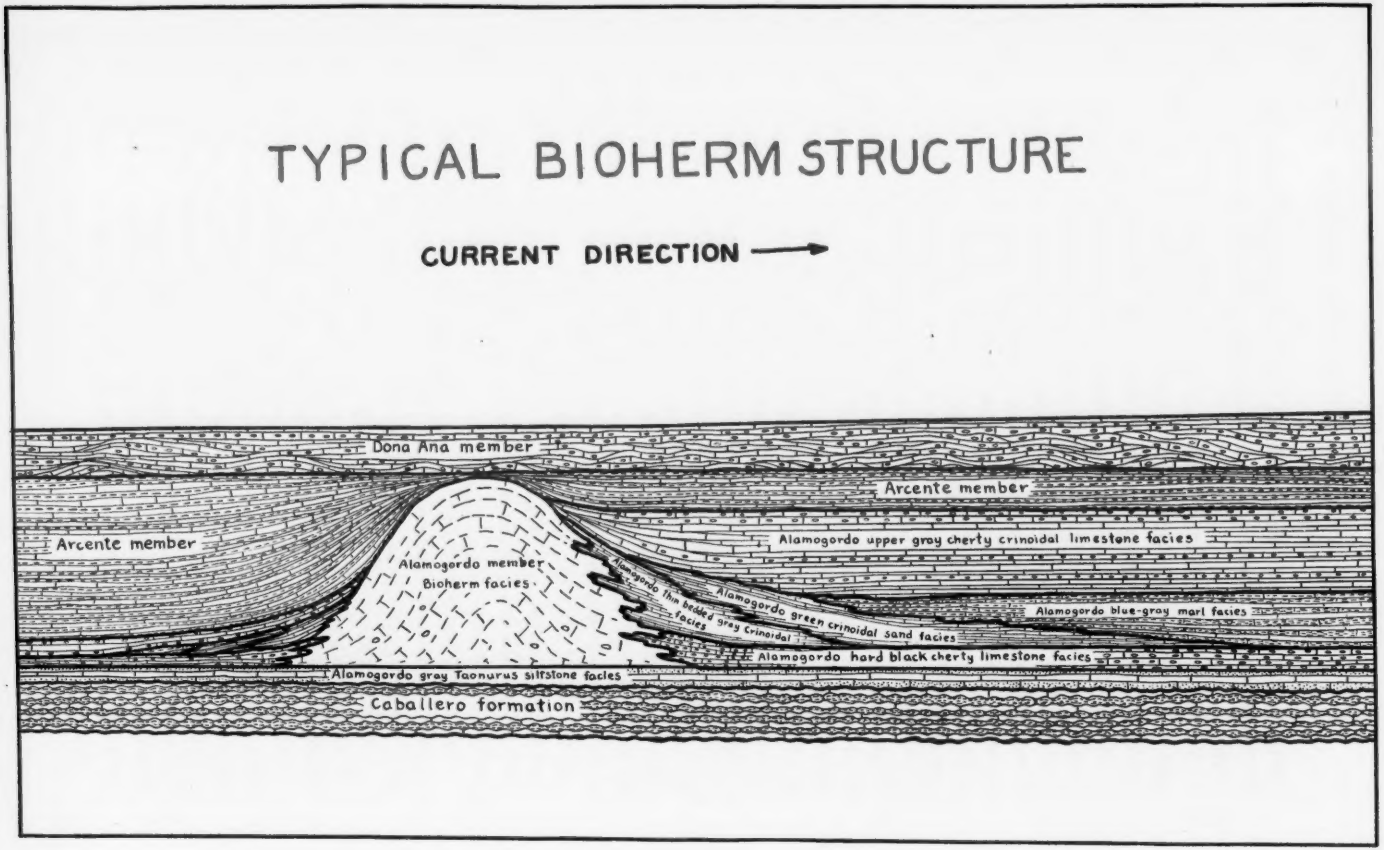

FIG. 10.—Typical bioherm structure.

contact with the bioherm facies. This would demand more than 150 feet of compaction in distances of less than ½ mile and the compaction would have to come simultaneously with deposition.

These facts, coupled with the normal bioherm deposition facies, indicate to us that the main bioherm structure rose as a distinct knob from the sea floor.

BIOHERM FACIES

The central mass, designated bioherm facies in this paper, consists of a rounded knob-like mass of black, hard, almost featureless limestone. There is a distinct absence of bedding in the structure, particularly toward the center. Toward the outer margins definite bedding can be recognized.

The bioherms vary in size from small masses about a foot in diameter to as much as 200 feet in thickness and a mile across the base. All of them are distinct, abrupt, conspicuous structures.

The bedding dips steeply away from the center and reaches as much as 40° near some of the outside margins.

The whole mass is distinctly and markedly unfossiliferous. The only fossils that occur in any considerable numbers are single isolated crinoid columnals. The fossils increase in number toward the outside margins.

The base of the structures tends to be flattened, suggesting that they reached their maximum width shortly after their inception. A few are definitely convex downward, showing expansion as they grew upward. A few of the bioherms seem to be developed on down through the basal black limestone facies well toward the base of the Alamogordo member. The tops are steeply rounded and dome shaped.

Because of the attitude of associated facies of sediments we have been forced to use definite current directions to explain the distribution of the associated sediments. The attitude of repose of sediments is steepest on the side from which the current comes. The steepest slopes of the bedding of the bioherm facies are found on the current side.

THIN-BEDDED, GRAY, CRINOIDAL FACIES

The bioherm facies grades laterally into the thin-bedded gray crinoidal facies on the back and lateral slopes of the bioherm. Minor beds probably referable to this facies are weakly developed on the current side of the bioherm. These beds grade into the bioherm facies, are definitely interbedded with and are of the same age as the bioherm facies. In a few places these beds are developed far in towards the center of the bioherm facies with the bioherm facies developed both above and below.

The thin-bedded gray crinoidal facies is made up almost entirely of fragmental and disintegrated parts of crinoids. It can be characterized as very coarsely crinoidal. The material is soft, and very loosely cemented together. Whole undamaged fossils are almost unknown in this facies. In spite of the fragmentary condition of the fossils they do not show evidence of having been transported far.

The fossils from which the facies developed apparently grew on the higher slopes of the bioherm and were carried slowly off the slope of the bioherm by the ocean currents after death of the animals.

GREEN CRINOIDAL SAND FACIES

The green crinoidal sand facies is closely associated with the thin-bedded gray crinoidal facies. It consists of thin-bedded very finely divided fragmental parts of crinoids colored green or blue-gray by simultaneous deposition and mixture with the normal marls that characterize the lagoonal areas between the bioherms.

This facies develops only locally in the area immediately behind the bioherm and far enough out from the bioherm so that only the finer crinoidal particles are mixed with the lagoon muds. Whole unbroken fossils occur only rarely in this facies.

LIMESTONE CONGLOMERATES

We have made no attempt to establish a limestone conglomerate facies because we have been unable to predict the exact position of limestone conglomerates in the bioherm structures.

Limestone conglomerates occur in connection with both the thin-bedded gray crinoidal facies and the green crinoidal sand facies. There seems to be no hard and fast rule with regard to their occurrence. They may occur as small local masses or they may occur as quite persistent beds of considerable thickness. They have been found wholly surrounded by the normal sediments of either of the two facies. Generally speaking they tend to occur rather far from the center of the bioherm mass.

They normally consist of relatively angular pieces of limestone from the underlying facies enclosed in a gray crinoidal or green crinoidal matrix. Most of the limestone pieces are relatively small in size.

The limestone conglomerates contain fairly well preserved fossils in the form of shells and crinoid calyces.

BLUE-GRAY MARL FACIES

The blue-gray marl facies is developed in the lagoon areas between the bioherm facies. The sediments of this facies interbed with the outer fringes of the green crinoidal sand facies or with the thin-

bedded gray crinoidal facies if the green crinoidal sand is not developed. This facies represents the finely divided muds deposited in the middle of the basin between the bioherms.

It consists of soft, thinly laminated, blue-gray to green, locally purple, pink, or red, very calcareous marl. Much of it is distinctly crinoidal. Some of the crinoidal material is fragmentary and some shows little disintegration. Some of the beds carry more lime, making them harder, which causes an uneven weathered slope.

It is in this facies that the excellent fossils are collected, and it is in this facies that the Lake Valley crinoids occur in the type section at Lake Valley. They apparently lived in this lagoonal environment and were buried here in the marls soon after death. They show no evidence of having been carried here from the bioherm.

This facies is soft and makes a definite retreating component of the Lake Valley section. It is commonly underlain by the massive projecting cliff of the hard black limestone facies and overhung by beds of the gray cherty crinoidal limestone facies.

UPPER GRAY CHERTY CRINOIDAL FACIES

We have included the upper gray cherty crinoidal facies as a distinct part of the Alamogordo member mainly because its development and thickness seem to be greatly influenced by the presence of bioherm structures. It is much better developed on the back side of the bioherm than on the current side. This facies is much more conspicuous, thicker, and more widely developed than the underlying facies.

It consists of normal, well bedded, gray, cherty, crinoidal limestone beds that do not differ much in lithology from the gray crinoidal beds of the Dona Ana member that caps the Lake Valley formation. These beds are lithologically like beds found in the Fern Glen and St. Joe formations of the Ozark area.

These beds gradually overlap on the underlying facies until eventually they come to cover the upper surface of the bioherm facies. On the current side, however, they are commonly much thinner in their development.

The exact origin of this facies and its relationships to the bioherm are confusing in the area where the bioherms are best developed. When considered regionally, however, it becomes a part of the normal sequence of deposition. In the bioherm area the normal sequence of deposition has been disturbed by the introduction of the bioherm structures and their associated facies.

Over much of the area in the southern part of the Sacramento

Mountains and in other areas such as the type area at Lake Valley, bioherm structures are not numerous. In these areas the hard black, cherty limestone facies of the Alamogordo member is directly overlain by a well developed blue-gray marl facies which in turn is overlain by the gray cherty crinoidal limestone facies.

The gray crinoidal limestone facies then may be considered as the return to normal sedimentation that had been disturbed by the introduction of the bioherm structure. Its only relationship to the bioherm is in thickness. Because of protection behind the bioherm structure marine organisms lived more prolifically resulting in a thicker accumulation of sediments here.

FAUNA OF ALAMOGORDO MEMBER

Some parts of the Alamogordo member are very fossiliferous. The main fauna has been collected from the blue-gray marl facies in the lagoonal areas. The upper gray crinoidal limestone is quite fossiliferous in some beds also.

Much of the Alamogordo fauna is new and a large number of species are transitional between known forms. Eighty-one species have been identified in the fauna. Of these only thirteen have been known to occur in Kinderhook rocks. The great preponderance of Osage species marks its position in the standard Mississippian column definitely as Osage. Only four of the listed species have been confined heretofore to the Kinderhook. The large crinoid fauna is with one exception of Osage age.

The question has arisen as to whether the *Taonurus* siltstone zone at the base of the Alamogordo member, should be classified with the underlying Caballero formation or with the Lake Valley formation. On the basis of its fauna as well as stratigraphic relations we have included it in the Lake Valley formation. We have identified 21 species of fossils from the *Taonurus* zone. Of these 19 occur in the Osage and 6 have been found in the Kinderhook. Only two of them have been heretofore restricted to the Kinderhook. The presence of such forms as *Zaphrentis cliffordana*, *Rhipidomella missouriensis*, *Dictyoclostus fernglenensis*, *Athyris lamellosa*, *Cliothyridina glenparkensis*, and *Ptychospira sexplicata* indicate strong Osage affinities.

The fauna of the Alamogordo member is all of early Osage age. The stage of evolution represented by the crinoids makes it unquestionably all pre-upper Burlington and probably entirely pre-Burlington in age. The greater number of the species are almost exact duplicates of those that occur in the St. Joe and Fern Glen limestones of the Ozark region.

Because of the considerable distance between the New Mexico area and the Upper Mississippi Valley and because of a considerable number of lower Burlington species that occur in the Alamogordo fauna, we can not make a positive correlation with any specific part of the standard Mississippi Valley section. Parts of the Alamogordo member are of St. Joe-Fern Glen age and part of it may be lower Burlington in age. Practically none of the typical upper Burlington forms occurs in the fauna. It is certainly not of Keokuk age as suggested by Keyes (19).

Arcente Member

Lithology.—The Arcente member is one of the most consistent lithologic units in the area. It consists of soft, dove-gray, relatively thin-bedded siltstone interbedded with almost an equal amount of soft dark silty shales. Because of its soft nature it weathers to blocky, rubbly, retreating slopes. In comparison with other parts of the section it is mostly free from chert although it does carry some black chert. In the lower part of the section the more resistant siltstone beds average about 3 inches in thickness. They are more massive toward the top of the formation and average about 9 inches in thickness. The interbedded shale deposits are progressively less conspicuous toward the top. The lower portion of the section is considerably more than 50 per cent shale. The coloration is not markedly different from that of the Caballero formation. The Arcente member, however, can be easily distinguished from the Caballero formation with its typical nodular bedding. The Arcente member is everywhere very evenly bedded.

Thickness.—The Arcente member exhibits abrupt lateral variations in thickness due to the underlying bioherm structures. It varies from a maximum of 230 feet in the type section area in Deadman Canyon to a few feet in the southern part of the range. On the sides of the bioherm structure in San Andreas Canyon it varies from 0 to a thickness of 155 feet in a distance of less than a mile. In the Marble Canyon area it is not present. The Pennsylvanian formations rest directly on the Alamogordo member.

Stratigraphic relations.—The exact stratigraphic relations between the Arcente member and the underlying Alamogordo member are difficult to determine. The great relief on the Alamogordo surface due to bioherm structure makes that Arcente member appear to overlie older beds with great disconformity. The stage of evolution of the fossils in both the Arcente and overlying Dona Ana members, however, is not greatly in advance of that of the Alamogordo members.

If the Arcente member overlies the Alamogordo with marked un-

Text Figure No. 11

FAUNA OF THE ALAMOGORDO MEMBER

1. Taonurus Siltstone Facies
2. Hard, Black, Cherty Limestone Facies
3. Green, Crinoidal Sand Facies
4. Blue-Gray, Shaly Marl Facies
5. Upper Gray Crinoidal Limestone Facies

	1	2	3	4	5
ANTHOZOA					
Cyathaxonia arcuatus				x	x
Zaphrentis centralis				x	x
Zaphrentis cliffordana	x	x		x	x
Triplophyllum dalei					x
Amplexus brevis					x
Amplexus blairi	x				
Favosites valmeyerensis	x			x	x
BRYOZOA					
Evactinopora sexradiata		x			x
Evactinopora quienqueradiata		x			
CRINOIDEA					
Rhodocrinus barrisi					x
Periechocrinus whitei			x	x	
Batocrinus curiosus				x	x
Batocrinus turbinatus					x
Uperocrinus robustus					x
Uperocrinus pyriformis			x		x
Uperocrinus aequibrachiatus				x	
Macrocrinus carica				x	x
Eutrochocrinus lovei				x	
Eutrochocrinus christyi			x		
Agaricocrinus pyramidatus					x
Agaricocrinus brevis					x
Agaricocrinus bellatrema				x	
Agaricocrinus prsecursor				x	
Agaricocrinus planoconvexus			x		
Aorocrinus subaculeatus				x	
Dorycrinus unicornis				x	
Actinocrinus rubra			x	x	
Actinocrinus smalleyi			x	x	x
Cactocrinus caelatus				x	
Steganocrinus pentagonus			x	x	x
Steganocrinus araneolus			x	x	
Physetocrinus ventricosus			x	x	
Physetocrinus copei			x		
Physetocrinus dilatatus			x		x
Amphoracrinus divergens					
Platycrinus verrucosus				x	
Platycrinus pociliformis			x	x	
Platycrinus asper				x	
Platycrinus nodo-striatus				x	
Platycrinus davisi			x	x	
Platycrinus springeri			x		
Platycrinus glyptus			x		
Platycrinus halli				x	
Platycrinus pileiformis			x		
Platycrinus burlingtonensis			x	x	x
Platycrinus sculptus				x	x
Platycrinus planus					x
Eucladocrinus tuberosus				x	x
Symbathocrinus wachsmuthi				x	
Symbathocrinus dentatus	x			x	
Coeliocrinus ventricosus				x	
BRACHIOPODA					
Crania blairi		x			
Leptaena analoga					x
Chonetes illinoisensis	x				
Chonetes missouriensis	x				
Schuchertella fernglenensis	x				
Rhipidomella missouriensis	x				x
Rhipidomella oweni	x				
Schizophoria poststriatula					x
Schizophoria swallovi				x	
Avonia laevicula	x				
Avonia concentrica					x
Productina sampsoni				x	x
Dictyoclostus fernglenensis	x	x			x
Dictyoclostus magnus					x
Echinoconchus alternatus					x
Dielasma osceolensis	x				
Rhynchopora persinuata				x	
Delthyris novamexicana	x				x
Spiriferina subelliptica	x				
Spirifer rowleyi	x		x	x	x
Spirifer shepardi	x				
Spirifer grimesi					x
Spirifer carinatus					x
Spirifer gregeri					x
Brachythyris suborbicularis	x	x			x
Pseudosyrinx missouriensis				x	x
Syringothyris textus					x
Athyris lamellosa	x	x		x	x
Cliothyridina glenparkensis	x			x	x
Cliothyridina obmaxima			x		x
Ambocoelia levicula					x
Ptychospira sexiplicata	x				
GASTROPODA					
Platyceras paralius	x			x	

FIG. 11.—Fauna of Alamogordo member.

conformity, the beds of the Arcente member should overlap against the Alamogordo surface. There should also be fragmentary material incorporated in the basal Arcente beds. Neither of these conditions has been observed at any place in the area. The basal Arcente beds everywhere lie flat against the steeply dipping sides of the bioherm structure and the thickening of the Arcente formation takes place by addition of beds within the formation. The change from crinoidal limestone to siltstone is sharp with no fragmentary material from the underlying formations being incorporated in the basal beds.

Text Figure No. 12

FAUNA OF THE ARCENTE MEMBER

ANTHOZOA
- Cyathaxonia arcuatus
- Zaphrentis cliffordana
- Cyathophyllum sp.
- Amplexus sp.
- Aulopora gracilis

BRYOZOA
- Fenestella (several species)

BRACHIOPODA
- Chonetes glenparkensis
- Dictyoclostus fernglenensis
- Avonia concentrica
- Rhipidomella missouriensis
- Schizophoria poststriatula
- Rhynchopora persinuata
- Dielasma sp.
- Delthyris novamexicana
- Spiriferina subelliptica
- Spirifer platynotus
- Spirifer rowleyi
- Spirifer louisianensis
- Spirifer schucherti
- Brachythyris chouteauensis
- Pseudosyrinx sampsoni
- Cliothyridina glenparkensis
- Ptychospira sexplicata

GASTROPODA
- Platyceras paralius
- Igoceras pabulocrinus

FIG. 12.—Fauna of Arcente member.

The only sign of disconformity between the formations is a persistent thin silty sandy zone at the base and local thin red oxidized streaks along the contact. Locally a few fragmentary fossil shells occur at the contact where the basal siltstone bed is slightly crinoidal and carries a large number of bryozoans.

In the San Andres Mountains in San Andres Canyon[4] the Arcente member overlies a bioherm structure with slightly more evidence of disconformity. A red oxidized zone marks the contact and in it are incorporated fragmentary shells, phosphatic concretions, and a few fish teeth.

Until further evidence is available, our interpretation is that there is little time break, if any, between the Arcente member and the underlying Alamogordo member.

[4] Not to be confused with the San Andreas Canyon in the Sacramento Mountains. The San Andres Canyon is in the San Andres Mountains on the west side of the Tularosa Valley; the San Andreas Canyon is in the Sacramento Mountains on the east side of the valley.

The Arcente member grades upward into the Dona Ana member with no signs of disconformity. It is generally difficult to place the contact between the members. The basal portion of the Dona Ana is in many places interbedded with silts very similar to those of the Arcente.

Paleontology.—The Arcente member is normally comparatively barren of fossils. The most conspicuous fossils in the member consist of large numbers of fenestelloid bryozoans. They are particularly abundant in the upper portion of the section. With time a relatively large molluscan fauna could be collected from the member. The crinoid fauna of the underlying Alamogordo member is missing. Of the 21 species of fossils listed from the Arcente member all have been known to occur in Osage formations. Seven have been listed from Kinderhook formations. All forms are characteristically early Osage in age.

Dona Ana Member

Lithology.—The Dona Ana member consists of relatively massive, gray-to-brown, coarsely crystalline, very cherty, crinoidal limestone. It crops out in bold massive overhanging cliffs. It is normally interbedded with dark crinoidal marl beds. The normal even bedding is generally complicated by the introduction of local small bioherm masses. The basal portion commonly contains much more soft marly material than the central portion which generally makes a vertical gray massive cliff. The upper portion is filled with large masses of light-colored chert. In some beds the limestone is almost completely replaced with these chert masses. Crinkly yellow and black chert is also present in the marl beds between the massive limestone ledges. The beds for the first 10 feet below the Pennsylvanian contact are commonly made up almost entirely of chert. This is not true in all areas. In some sections, particularly farther toward the south, the upper portion of the Dona Ana consists of massive, gray-to-brown, coarsely crystalline, crinoidal limestone.

Thickness.—The thickness of the Dona Ana member apparently is dependant to a great extent on the amount of pre-Pennsylvanian erosion in the area where the section is being measured. In the Marble Canyon area in the northern end of the range the Dona Ana member is missing entirely. In the type section area in Deadman canyon it is 60 feet thick. The maximum sections are exposed considerably farther south in the vicinity of San Andreas and Dog canyons. In the measured San Andreas Canyon section it is 175 feet thick. South of Dog Canyon it thins abruptly and is apparently not present south of Escondido Canyon.

Stratigraphic relations.—The contact of the Dona Ana member with the underlying Arcente member is conformable. The Arcente member grades insensibly up into the Dona Ana. It is difficult to establish a contact in normal sections.

Text Figure No. 13

FAUNA OF THE DONA ANA MEMBER

ANTHOZOA
Zaphrentis cliffordana
Zaphrentis centralis
Triplophyllum dalei
CRINOIDEA
Rhodocrinus tuberculatus
Eutrochocrinus christyi
Eutrochocrinus christyi var. trochiscus
Eretmocrinus n. sp.
Eretmocrinus remibranchiatus var. expansus
Uperocrinus pyriformis n. var. 1
Uperocrinus pyriformis n. var. 2
Uperocrinus pistillus n. var.
Agaricocrinus planoconvexus
Agaricocrinus excavatus
Cactocrinus sp.
Steganocrinus sp.
Physetocrinus ventricosus
Platycrinus glyptus
BRACHIOPODA
Rhipidomella oweni
Rhipidomella jerseyensis
Echinoconchus alternatus
Rhynchopora persinuata
Tetracamera subtrigona
Spirifer grimesi
Spirifer rowleyi
Brachythyris suborbicularis
Athyris lamellosa
Cliothyridina obmaxima
GASTROPODA
Platyceras paralius

FIG. 13.—Fauna of Dona Ana member.

The contact of the Dona Ana with the overlying Pennsylvanian strata is sharply unconformable. Widely varying members of the Pennsylvanian formations are found in contact with the Dona Ana or lower Mississippian members within very short distances. Chert conglomerates are found in many places in the base of the Pennsylvanian formations, particularly where erosion has cut deeply into the Mississippian section.

Where the Dona Ana member is thickest the Pennsylvanian formations appear to lie on the Dona Ana with least obvious evidence of unconformity. This is because all fragmentary material was swept off

from the high parts of the Mississippian erosion surface and the Pennsylvanian limestones were laid down directly in contact with fresh Mississippian limestones. The greatest evidences of unconformity appear on the slopes or in the valleys of the erosion surface.

Paleontology.—The Dona Ana member is fossiliferous throughout. Fragmentary crinoidal material may be found at almost any point. Some of the beds carry rich coral and shell faunas. Local lenses produce excellent crinoid calyces.

A far larger faunal list could be assembled from the Dona Ana member if extensive work were done on the entire member. In most areas the Dona Ana is represented by an almost vertical cliff, making the greater part of the section unavailable for fossil collecting.

We have identified 24 species of invertebrates from the Dona Ana beds and all are typical Osage forms. A large percentage of our Dona Ana forms are not listed because they represent new species and new varieties. The Dona Ana fauna is very interesting so far as the crinoid fauna is concerned in that we have a large number of forms transitional to commonly recognized species found in the Burlington formation.

An analysis of the Dona Ana fauna shows nothing younger than lower Burlington. The fauna is typical of that of the lower Burlington formation as exposed in the Upper Mississippi Valley. There is absolutely no representation whatsoever of the bizarre upper Burlington crinoid fauna which in the Mississippi Valley region is characterized by such forms as *Actinocrinus multiradiatus*, *Actinocrinus verrocosus*, *Teleiocrinus umbrosus*, *Teleiocrinus rudis*, *Strotocrinus glyptus*, and *Dorycrinus cornigerus*.

If we were working in the type area in the Upper Mississippi Valley, we would not hesitate to place the fauna as characteristic of the upper portion of the lower Burlington which in that area is referred to the *Physetocrinus* zone (23).

The Lake Valley formation of the Sacramento Mountain area according to our interpretation represents strata from earliest Osage age, perhaps older than anything represented in the Fern Glen or St. Joe sections, up to the upper portion of the lower Burlington formation of the Mississippi Valley area. This interpretation is considerably different from that of Keyes (15) who assigns these strata to the Keokuk formation.

MARBLE CANYON SECTION

The Marble Canyon area in the northern part of the range is complicated by the presence of several bioherms. In the canyons north of

Marble Canyon the bioherm structures are even more abundant than in the Marble Canyon area. In this area the bioherms are so close together that offshore facies of one bioherm grade into offshore facies of

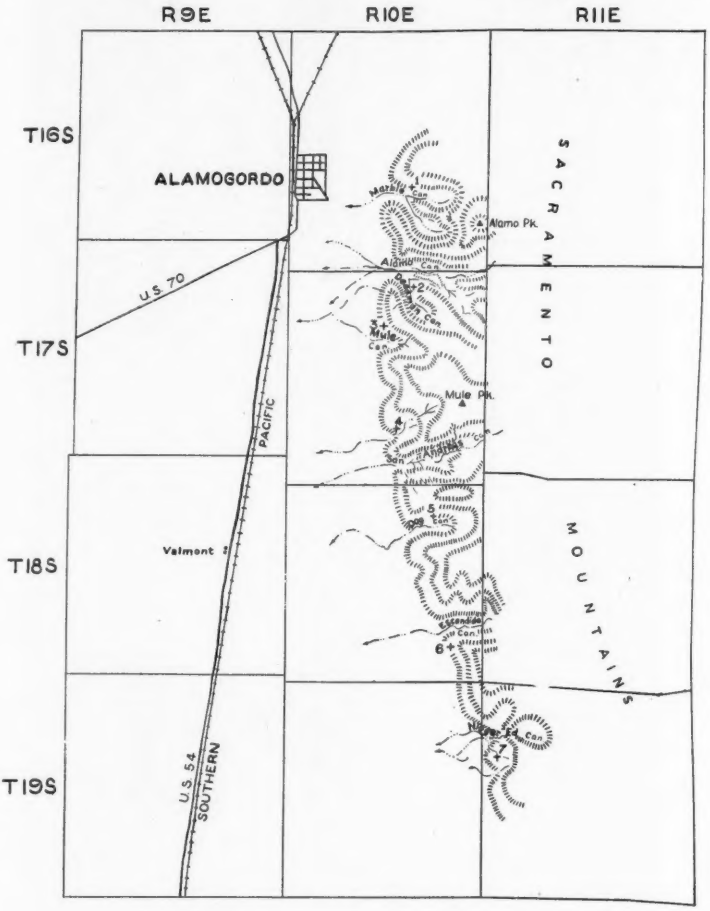

FIG. 14.—Map showing location of measured sections.

1. Marble Canyon section
2. Deadman Canyon section
3. Mule Canyon section
4. San Andreas Canyon section
5. Dog Canyon section
6. Escondido Canyon section
7. Nigger Ed Canyon section

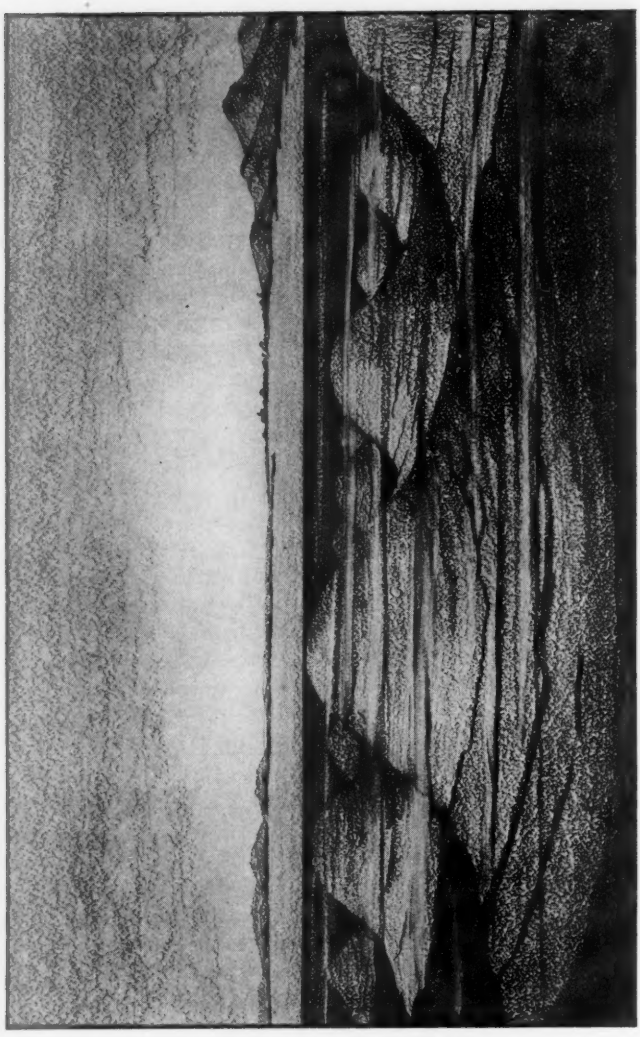

FIG. 15.—Diagrammatic illustration of appearance of sea bottom in Marble Canyon area in Mississippian time. Drawn by Ed. Albin, University of Tulsa Art Department.

the adjacent bioherm, greatly complicating the stratigraphic picture.

The composite Marble Canyon section was measured along the mountain front and north canyon wall in Marble Canyon. The Lake

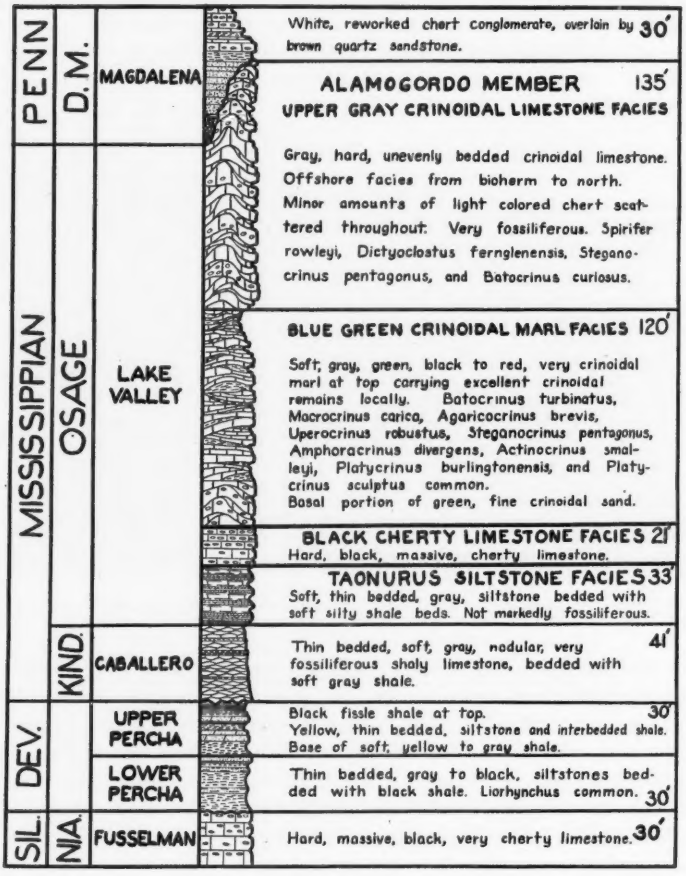
PENN
D.M.
MAGDALENA
White, reworked chert conglomerate, overlain by brown quartz sandstone. 30'
ALAMOGORDO MEMBER 135'
UPPER GRAY CRINOIDAL LIMESTONE FACIES
Gray, hard, unevenly bedded crinoidal limestone. Offshore facies from bioherm to north. Minor amounts of light colored chert scattered throughout. Very fossiliferous. Spirifer rowleyi, Dictyoclostus ferrnglenensis, Steganocrinus pentagonus, and Batocrinus curiosus.
MISSISSIPPIAN
OSAGE
LAKE VALLEY
BLUE GREEN CRINOIDAL MARL FACIES 120'
Soft, gray, green, black to red, very crinoidal marl at top carrying excellent crinoidal remains locally. Batocrinus turbinatus, Macrocrinus carica, Agaricocrinus brevis, Uperocrinus robustus, Steganocrinus pentagonus, Amphoracrinus divergens, Actinocrinus smalleyi, Platycrinus burlingtonensis, and Platycrinus sculptus common.
Basal portion of green, fine crinoidal sand.
BLACK CHERTY LIMESTONE FACIES 2'
Hard, black, massive, cherty limestone.
TAONURUS SILTSTONE FACIES 33'
Soft, thin bedded, gray, siltstone bedded with soft silty shale beds. Not markedly fossiliferous.
KIND.
CABALLERO
Thin bedded, soft, gray, nodular, very fossiliferous shaly limestone, bedded with soft gray shale. 41'
DEV.
UPPER PERCHA
Black fissle shale at top. 30'
Yellow, thin bedded, siltstone and interbedded shale. Base of soft, yellow to gray shale.
LOWER PERCHA
Thin bedded, gray to black, siltstones bedded with black shale. Liorhynchus common. 30'
SIL.
NIA.
FUSSELMAN
Hard, massive, black, very cherty limestone. 30'

FIG. 16.—Marble Canyon section, SE. ¼ of SE. ¼ of Sec. 22, T. 16 S., R. 10 E.

Valley portion of the section was measured in the immediate vicinity of the old marble quarry in the north canyon wall about ½ mile up from the canyon mouth.

The basal portion of the Lake Valley formation is normal, carrying *Taonurus* siltstone facies and the hard black cherty limestone

facies. The upper portion of the Lake Valley section is related to a large bioherm that is buried beneath the hill northeast of the quarry. The bioherm facies is not exposed in this area. By following the small creek immediately above the quarry back to the northeast, the upper gray crinoidal facies can be seen rising steeply against the bioherm structure although the bioherm facies is not exposed.

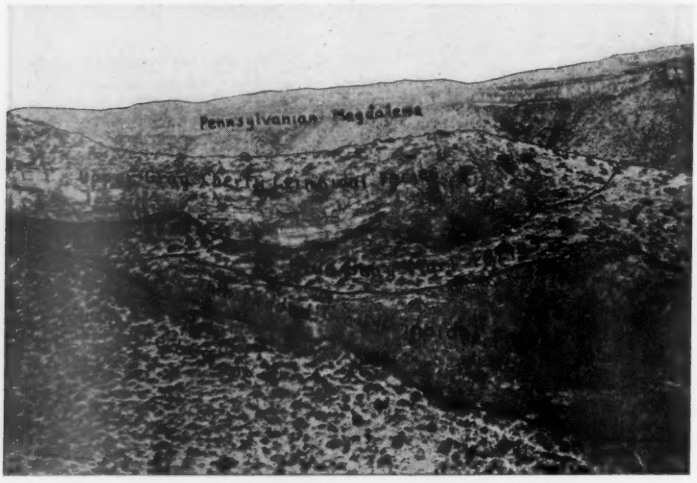

FIG. 17.—Picture showing thin-bedded gray crinoidal limestone facies in south wall of north branch of Marble Canyon.

On the north canyon wall at the entrance to the canyon the black cherty limestone facies is overlain by a thin remnant of the thin-bedded gray crinoidal facies, which in turn is overlain by the green crinoidal marl facies. The hill is capped with a thin remnant of the upper gray crinoidal limestone facies. In the second gully to the north along the mountain front from Marble Canyon the blue-green marly facies grades into the green crinoidal sand facies. Excellent exposures of this facies may be seen in this gully.

An excellent example of the abruptness with which facies change with respect to bioherm structures may be seen on the south canyon wall in the north branch of Marble Canyon about a half mile above the quarry. Here the canyon has cut a section entirely across the lower thin-bedded gray crinoidal limestone facies.

The entrance to the south branch of Marble Canyon lies immediately across from the quarry. Another excellent bioherm may be seen

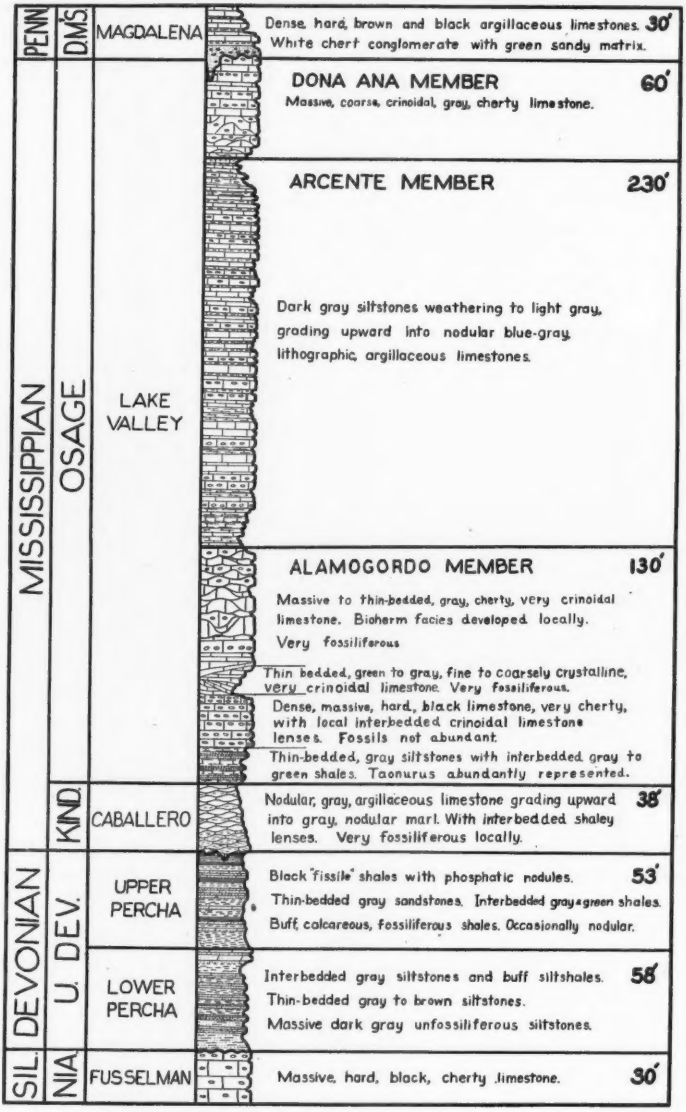
PENN
DMS.
MAGDALENA
Dense, hard, brown and black argillaceous limestones. 30'
White chert conglomerate with green sandy matrix.
MISSISSIPPIAN
OSAGE
LAKE VALLEY
DONA ANA MEMBER 60'
Massive, coarse, crinoidal, gray, cherty limestone.
ARCENTE MEMBER 230'
Dark gray siltstones weathering to light gray, grading upward into nodular blue-gray lithographic, argillaceous limestones.
ALAMOGORDO MEMBER 130'
Massive to thin-bedded, gray, cherty, very crinoidal limestone. Bioherm facies developed locally.
Very fossiliferous
Thin bedded, green to gray, fine to coarsely crystalline, very crinoidal limestone. Very fossiliferous.
Dense, massive, hard, black limestone, very cherty, with local interbedded crinoidal limestone lenses. Fossils not abundant
Thin-bedded, gray siltstones with interbedded gray to green shales. Taonurus abundantly represented.
KIND.
CABALLERO
Nodular, gray, argillaceous limestone grading upward into gray, nodular marl. With interbedded shaley lenses. Very fossiliferous locally. 38'
DEVONIAN
U. DEV.
UPPER PERCHA
Black "fissile" shales with phosphatic nodules. 53'
Thin-bedded gray sandstones. Interbedded gray-green shales.
Buff, calcareous, fossiliferous shales. Occasionally nodular.
LOWER PERCHA
Interbedded gray siltstones and buff siltshales. 58'
Thin-bedded gray to brown siltstones.
Massive dark gray unfossiliferous siltstones.
SIL.
NIA
FUSSELMAN
Massive, hard, black, cherty limestone. 30'

FIG. 18.—Deadman Canyon section, SE. ¼ of NW. ¼ of Sec. 3, T. 17 S., R. 10 E.

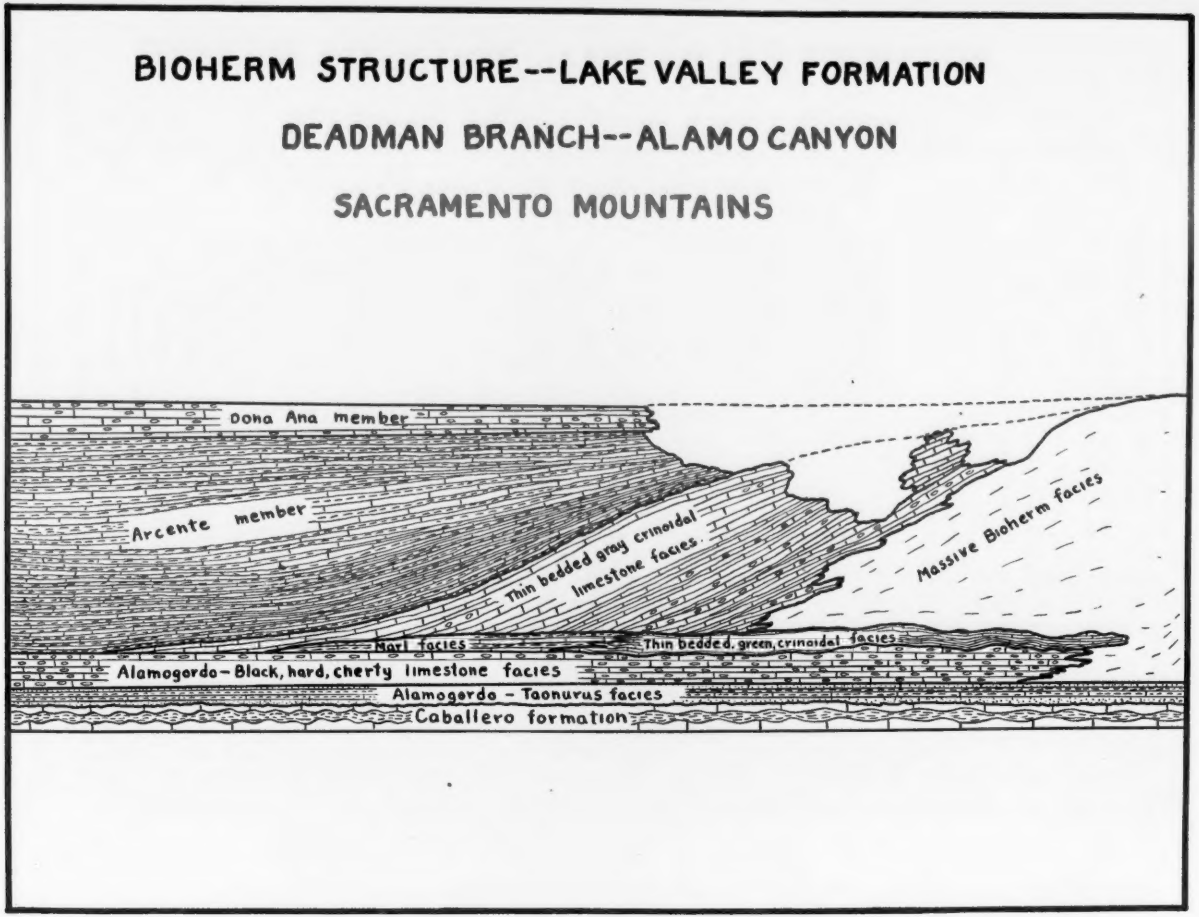

FIG. 19.—Bioherm structure—Lake Valley formation, Deadman Branch, Alamo Canyon, Sacramento Mountains.

about a half mile up this canyon. The bioherm facies is completely dissected by the canyon and the associated facies are exposed on either wall.

The Pennsylvanian contact is excellently exposed along the walls of the creek immediately above the quarry in Marble Canyon. The base of the Pennsylvanian is marked by a thick chert conglomerate, which is overlain by a brown quartz sandstone, which, in turn, is overlain by the normal shales and black cherty limestones. All of these facies may be seen in contact with the underlying Mississippian formations in a very short distance along this creek valley. Excellent exposures are visible.

FIG. 20.—Picture taken near mouth at Deadman Canyon looking northeast across Alamo Canyon. The type sections in Deadman Canyon are at the right, up Deadman Canyon.

DEADMAN CANYON SECTION

The Deadman Canyon section has been described in detail in connection with the type sections of the various members of the Lake Valley formation.

Quite confusing stratigraphic relations are found in Deadman Canyon. The canyon splits into three branches near its head. The southernmost and lefthand branch cuts directly up through the bioherm facies of a large bioherm, exposing it excellently. The entire south canyon wall out to the mountain front is capped with massive limestones of the upper gray cherty crinoidal facies. Pennsylvanian strata rest directly on this facies along this wall.

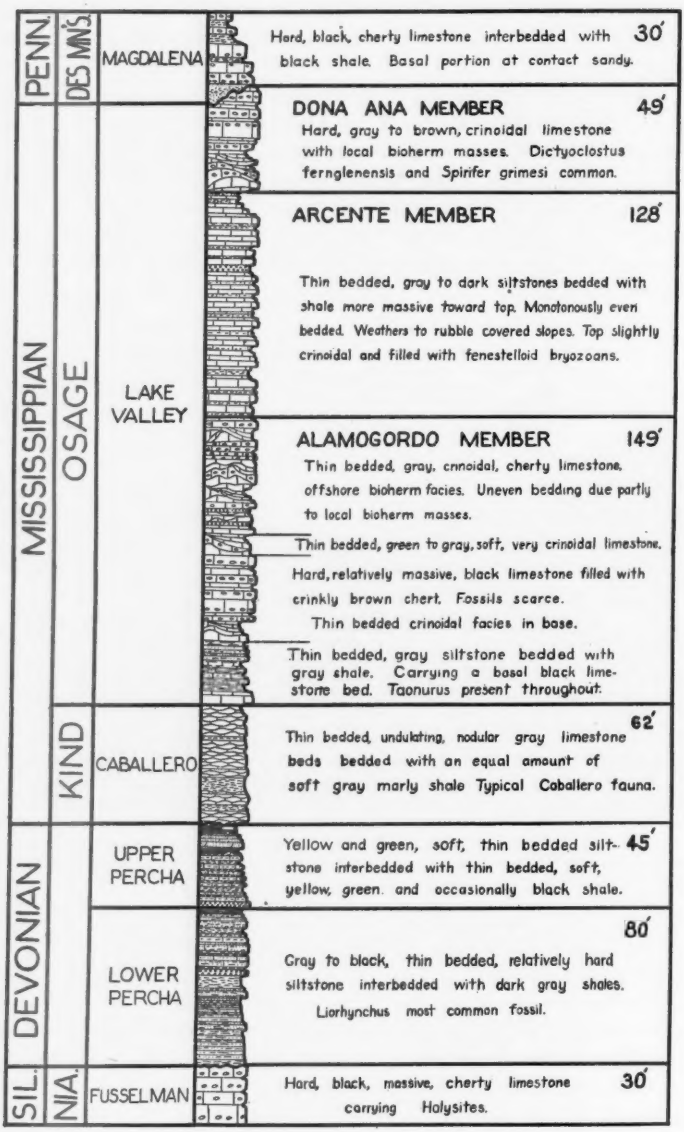
PENN.
DES MNS.
MAGDALENA
Hard, black, cherty limestone interbedded with black shale. Basal portion at contact sandy. 30'
MISSISSIPPIAN
OSAGE
LAKE VALLEY
DONA ANA MEMBER 49'
Hard, gray to brown, crinoidal limestone with local bioherm masses. Dictyoclostus fernglenensis and Spirifer grimesi common.
ARCENTE MEMBER 128'
Thin bedded, gray to dark siltstones bedded with shale more massive toward top. Monotonously even bedded. Weathers to rubble covered slopes. Top slightly crinoidal and filled with fenestelloid bryozoans.
ALAMOGORDO MEMBER 149'
Thin bedded, gray, crinoidal, cherty limestone, offshore bioherm facies. Uneven bedding due partly to local bioherm masses.
Thin bedded, green to gray, soft, very crinoidal limestone.
Hard, relatively massive, black limestone filled with crinkly brown chert. Fossils scarce.
Thin bedded crinoidal facies in base.
Thin bedded, gray siltstone bedded with gray shale. Carrying a basal black limestone bed. Taonurus present throughout.
KIND
CABALLERO
62'
Thin bedded, undulating, nodular gray limestone beds bedded with an equal amount of soft gray marly shale Typical Caballero fauna.
DEVONIAN
UPPER PERCHA
45'
Yellow and green, soft, thin bedded siltstone interbedded with thin bedded, soft, yellow, green and occasionally black shale.
LOWER PERCHA
80'
Gray to black, thin bedded, relatively hard siltstone interbedded with dark gray shales.
Liorhynchus most common fossil.
SIL.
NIA.
FUSSELMAN
Hard, black, massive, cherty limestone carrying Halysites. 30'

FIG. 21.—Mule Canyon section, center of W. ½ of NW. ¼ of Sec. 9, T. 17 S., R. 10 E.

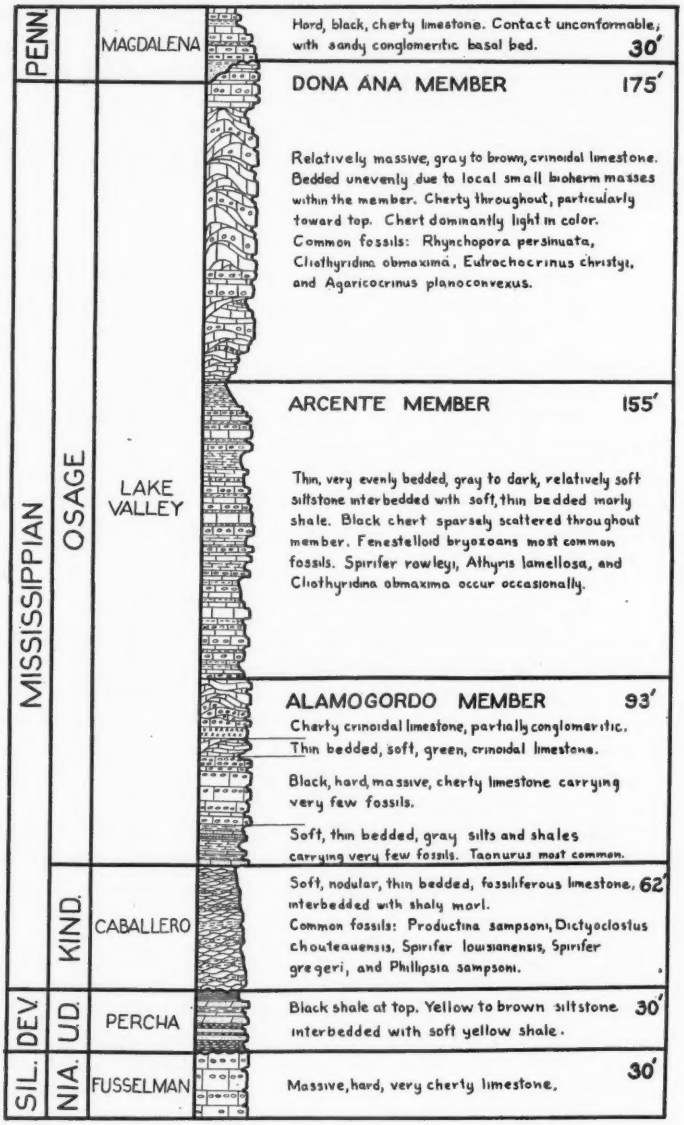
PENN
MISSISSIPPIAN
OSAGE
KIND.
DEV.
U.D.
SIL.
NIA.
MAGDALENA
LAKE VALLEY
CABALLERO
PERCHA
FUSSELMAN
Hard, black, cherty limestone. Contact unconformable; with sandy conglomeritic basal bed. 30'
DONA ANA MEMBER 175'
Relatively massive, gray to brown, crinoidal limestone. Bedded unevenly due to local small bioherm masses within the member. Cherty throughout, particularly toward top. Chert dominantly light in color. Common fossils: Rhynchopora persinuata, Cliothyridina obmaxima, Eutrochocrinus christyi, and Agaricocrinus planoconvexus.
ARCENTE MEMBER 155'
Thin, very evenly bedded, gray to dark, relatively soft siltstone interbedded with soft, thin bedded marly shale. Black chert sparsely scattered throughout member. Fenestelloid bryozoans most common fossils. Spirifer rowleyi, Athyris lamellosa, and Cliothyridina obmaxima occur occasionally.
ALAMOGORDO MEMBER 93'
Cherty crinoidal limestone, partially conglomeritic.
Thin bedded, soft, green, crinoidal limestone.
Black, hard, massive, cherty limestone carrying very few fossils.
Soft, thin bedded, gray silts and shales carrying very few fossils. Taonurus most common.
Soft, nodular, thin bedded, fossiliferous limestone, interbedded with shaly marl. 62'
Common fossils: Productina sampsoni, Dictyoclostus chouteauensis, Spirifer louisianensis, Spirifer gregeri, and Phillipsia sampsoni.
Black shale at top. Yellow to brown siltstone interbedded with soft yellow shale. 30'
Massive, hard, very cherty limestone. 30'

FIG. 22.—San Andreas Canyon section, center of W. ½ of SW. ½ of Sec. 27, T. 17 S., R. 10 E.

The Arcente and Dona Ana members are exposed only along the northeast canyon wall about ½ mile north of the exposure of the bioherm facies where they may be seen dipping steeply off the bioherm structure in this area. The best exposures of these two upper members are in the gullies around past the north side of the knob of limestone that lies at the north side of the entrance to the northernmost or righthand branch of Deadman Canyon.

MULE CANYON SECTION

Mule Canyon is the first main canyon south of Alamo Canyon. The rock section exposed in this area is normal, apparently unaffected by bioherm structure in the immediate vicinity.

The upper portion of the Arcente member in this area is interbedded with shaly zones which carry large fenestelloid bryozoan colonies. The entire upper portion of the member is characterized by this fauna.

A large number of green basic igneous sills have been injected at various intervals through the section. They may be found throughout the entire Sacramento Mountain area but are more abundant in this area.

SAN ANDREAS CANYON SECTION

The San Andreas Canyon section was not measured in San Andreas Canyon but in the first small re-entrant into the mountain front about ½ mile north of the entrance to San Andreas Canyon. The actual measured section was located on the north canyon wall about ½ mile east of the large conspicuous bioherm that may be seen at the entrance to this small canyon. The last remaining offshore facies of this bioherm is represented in the top of the Alamogordo member.

The lower portion of the Dona Ana member in this area is shaly and crinoidal. Much of this material is excellently fossiliferous. By splitting the weathered blocks of this crinoidal limestone an excellent fauna may be collected.

SAN ANDREAS CANYON BIOHERM

One of the most spectacular bioherms in the entire Sacramento Mountains is located in the north wall of the mountain front at the entrance to this first small canyon north of San Andreas Canyon. It is so spectacularly developed that it can be seen from the El Paso-Alamogordo highway. The bioherm facies has been eroded out from the mountain front and stands out conspicuously from the other part of the section.

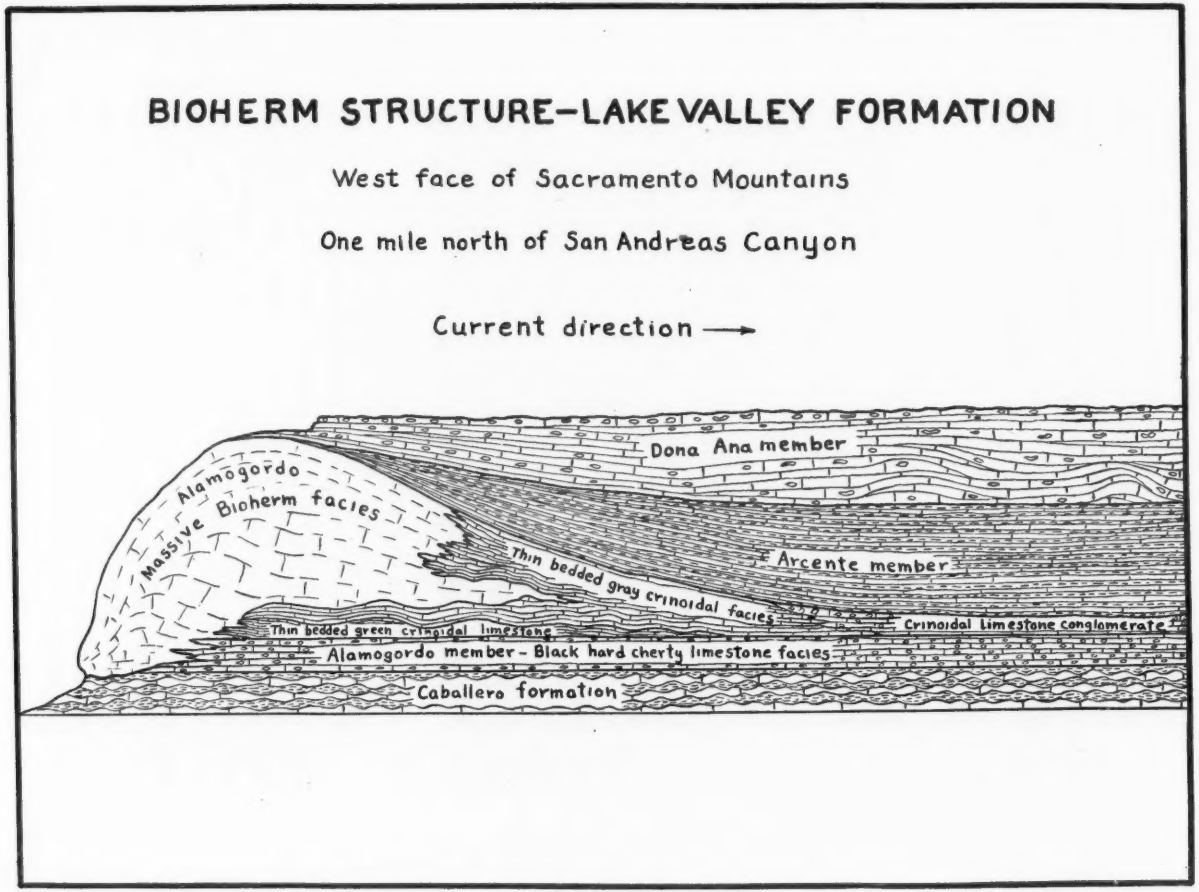

FIG. 23.—Bioherm structure, Lake Valley formation, west face of Sacramento Mountains, 1 mile north of San Andreas Canyon.

The bioherm facies is about 200 feet in maximum thickness. It cuts down through the hard black cherty limestone facies on a limited area near its western extremity. Due to this early development of the bioherm facies a local thin-bedded crinoidal facies developed behind the embryonic bioherm that was later totally overgrown by the larger main bioherm facies. This appears now as a curving stringer of thin-bedded crinoidal limestone that cuts far back under the east side of the structure between the bioherm facies and the hard black cherty limestone facies.

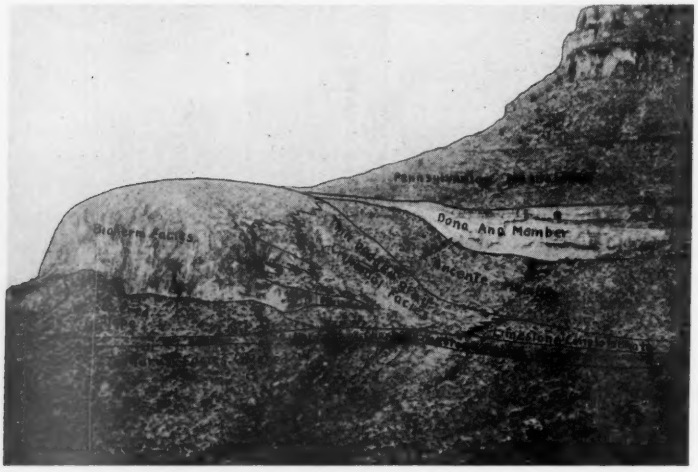

FIG. 24.—San Andreas bioherm. Picture taken from the southeast.

This bioherm does not exhibit full development. The thin-bedded gray crinoidal facies is excellently developed. It grades outward into a local green crinoidal sand facies which grades shortly into a thin development of the blue-green marl facies. Both the green crinoidal sand facies and the blue-gray marl facies are weakly developed. The upper gray, cherty, crinoidal limestone facies is entirely missing. The conspicuous bald knob of the bioherm facies with its associated thin-bedded crinoidal facies is overlapped with steeply dipping beds of the Arcente member. The Dona Ana member rises only slightly above the top of the bioherm facies. In the lagoonal area the base of the Dona Ana lies lower than the top of the near-by bioherm facies.

DOG CANYON SECTION

The Dog Canyon section was measured on the north canyon wall about one mile above the entrance to the canyon. The sedimentation

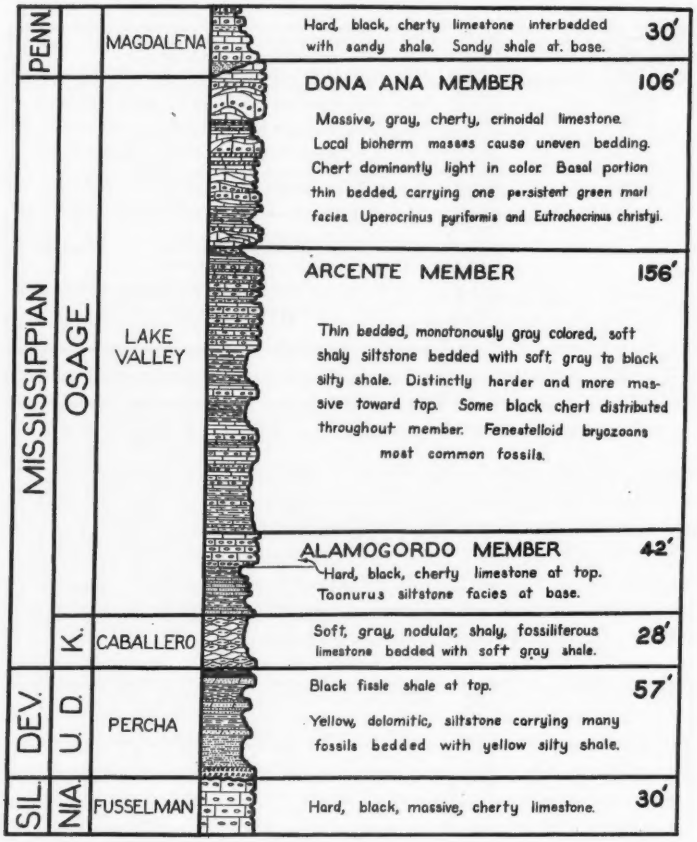
PENN
MISSISSIPPIAN
DEV.
SIL.
OSAGE
U. D.
NIA.
K.
MAGDALENA
LAKE VALLEY
CABALLERO
PERCHA
FUSSELMAN
Hard, black, cherty limestone interbedded with sandy shale. Sandy shale at base. 30'
DONA ANA MEMBER 106'
Massive, gray, cherty, crinoidal limestone. Local bioherm masses cause uneven bedding. Chert dominantly light in color. Basal portion thin bedded, carrying one persistent green marl facies. Uperocrinus pyriformis and Eutrochocrinus christyi.
ARCENTE MEMBER 156'
Thin bedded, monotonously gray colored, soft shaly siltstone bedded with soft, gray to black silty shale. Distinctly harder and more massive toward top. Some black chert distributed throughout member. Fenestelloid bryozoans most common fossils.
ALAMOGORDO MEMBER 42'
Hard, black, cherty limestone at top. Taonurus siltstone facies at base.
Soft, gray, nodular, shaly, fossiliferous limestone bedded with soft gray shale. 28'
Black fissle shale at top. 57'
Yellow, dolomitic, siltstone carrying many fossils bedded with yellow silty shale.
Hard, black, massive, cherty limestone. 30'

FIG. 25.—Dog Canyon section, center of S. ½ of NE. ¼ of Sec. 10, T. 18 S., R. 10 S.

represented in the Dog Canyon section is normal and uncomplicated by bioherm structure. The Arcente member is excellently developed although not as thick as in San Andreas Canyon.

The Dona Ana section carries two local thin-bedded, dark-colored, shaly, crinoidal zones from which rather nice faunas may be obtained.

ESCONDIDO CANYON SECTION

In the southern end of the Sacramento Mountains the Mississippian formations are only thinly developed. The Caballero formation is nearly as thick as it is in most of the northern area. It is by far the most

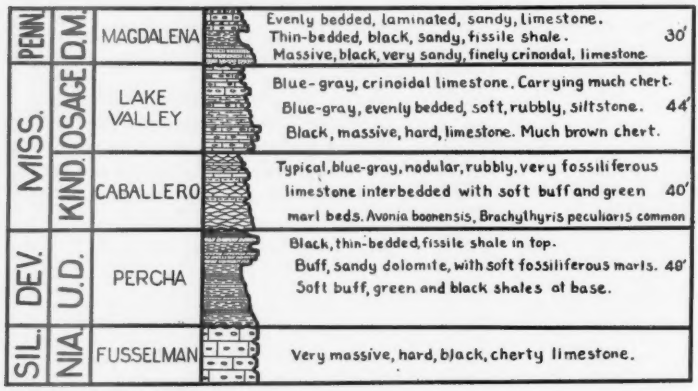

FIG. 26.—Escondido Canyon section, SE. ¼ of Sec. 27, T. 18 S., R. 10 E.

conspicuous part of the Mississippian section in the southern area. It still retains its distinctive lithology and fauna. The Lake Valley beds are entirely confined to the Alamogordo member of the formation. The *Taonurus* siltstone is absent. The basal hard black cherty limestone beds lie directly on the Caballero formation. It is overlain by crinoidal beds that carry an Alamogordo fauna. It is not possible to tell what part of the northern section they represent.

FIG. 27.—Nigger Ed Canyon section, NE. ¼ of NW. ¼ of Sec. 18, T. 18 S., R. 11 E.

NIGGER ED CANYON SECTION

The Nigger Ed Canyon section is the southernmost section measured in the Sacramento Mountains. About 2 miles south of Nigger Ed

Canyon the Mississippian formations plunge beneath the alluvium on the valley floor.

The Caballero formation retains its typical nodular lithology and fauna although it is considerably thinner in this area.

The Lake Valley formation can be recognized only by its typical crinoidal lithology and a few persistent fossils. The basal black cherty limestones of the Escondido Canyon area on the north are missing or at least only thinly developed. A shaly crinoidal marl is introduced into the central portion of the section which is capped by cherty crinoidal limestone. It is not possible to correlate this section with any specific part of the Lake Valley formation on the north. It undoubtedly represents the southern extension of the Alamogordo member.

San Andres Mountain Area

We have made a few preliminary reconnaissance trips into various parts of the San Andres Mountain area. The best section we have encountered as yet is located in San Andres Canyon. The canyon cuts a cross section through a typical bioherm near the center of the range.

The Caballero formation is excellently developed in this area, measuring 71 feet in thickness. It carries a typical though not abundant fauna. It is much more evenly bedded and the nodular bedding so characteristic of the Sacramento region is largely missing. Parts of the section still carry the nodular bedding, however.

The *Taonurus* siltstone facies of the Alamogordo member is not developed. The hard black cherty limestone facies of the Alamogordo member is unusually well developed in this area. It makes a very conspicuous ledge along the whole canyon wall, averaging 65 feet in thickness.

A typical bioherm facies is present in the section. It so happens that the apex of the bioherm comes at a position where the structure of the formations plunges abruptly toward the valley floor. This complicates the picture slightly because the current side of the bioherm is on the side toward which the structure is pitching.

The thin-bedded crinoidal facies and the blue-gray marl facies are excellently developed on the back of the bioherm. A large typical Alamogordo crinoid fauna was collected from the blue-gray marl facies. The lithology and fauna here are closely similar to those in which the crinoid faunas occur at Lake Valley. This section offers the best evidence of the actual age of the different members as exposed at Lake Valley.

The maximum thickness of the Lake Valley section in San Andres Canyon is 238 feet. The Arcente member is definitely present at the top. Its lithology here is identical with that of the Sacramento Moun-

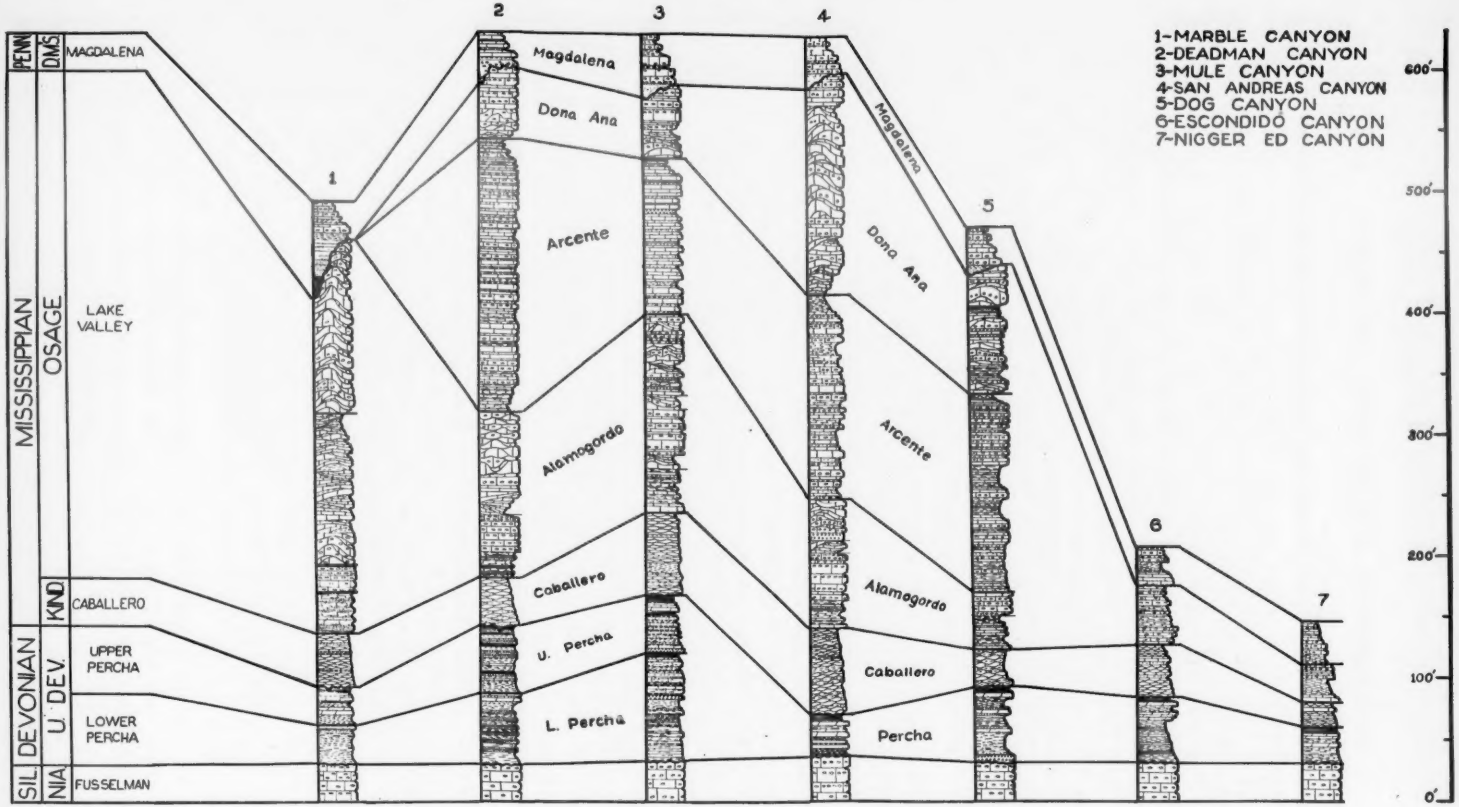

FIG. 28.—Correlation chart of Sacramento Mountains area. Chart showing relationships of the various Mississippian formations in the Sacramento Mountains.

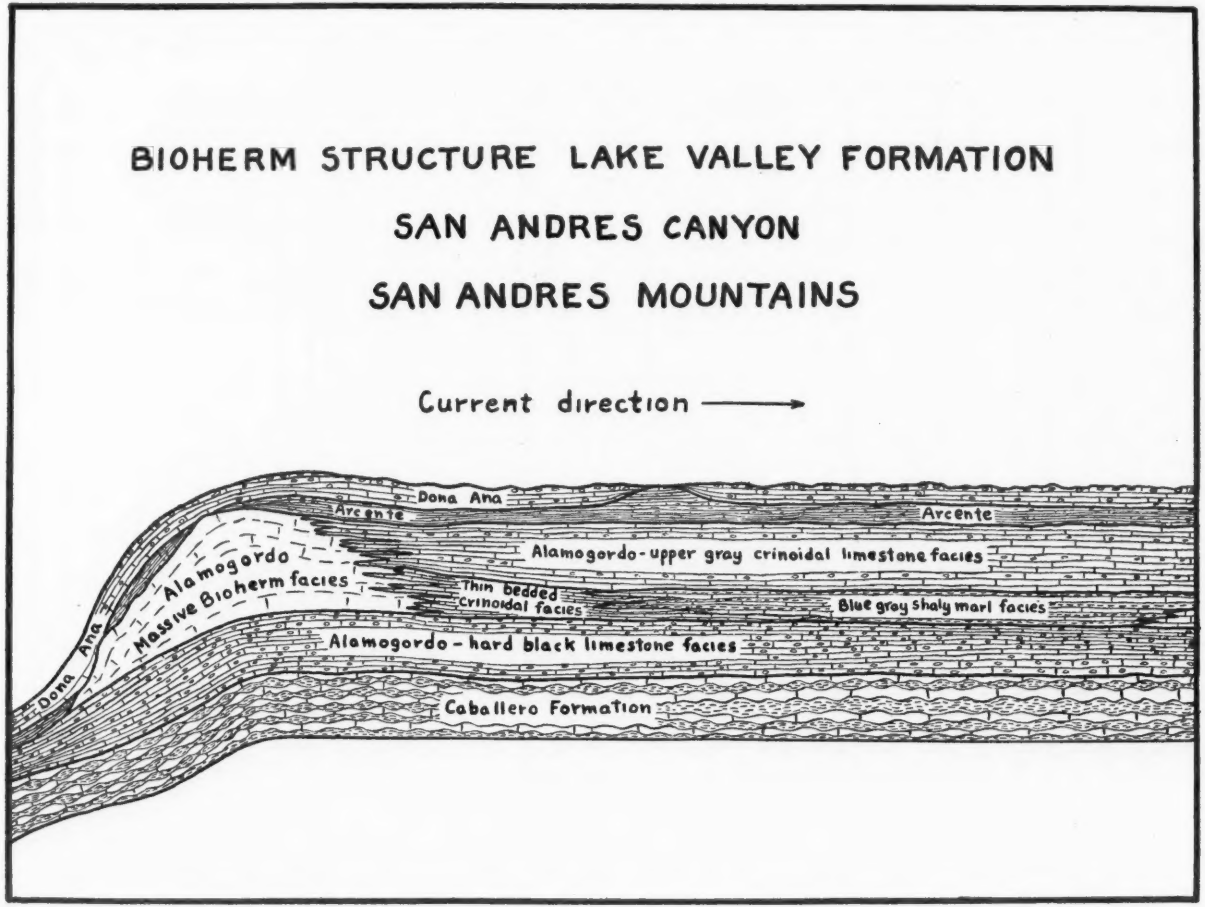

FIG. 29.—Bioherm structure, Lake Valley formation, San Andres Canyon, San Andres Mountains.

tains. Local evidence of unconformity between the Dona Ana member and the Arcente member is seen in this area. Local hills appear to be left on the Arcente surface and the Dona Ana member overlaps them. The Arcente member is excellently fossiliferous here.

The Dona Ana member is only thinly developed. It consists of typical cherty crinoidal limestone and carries a fauna similar to the one carried in the Sacramento Mountains.

Text Figure number 30

FAUNA OF THE BLUE GRAY MARL FACIES
SAN ANDRES CANYON, SAN ANDRES MOUNTAINS

ANTHOZOA
- Zaphrentis cliffordana

CRINOIDEA
- Agaricocrinus pyramidatus
- Cactocrinus multibrachiatus
- Steganocrinus pentagonus
- Steganocrinus araneolus
- Physetocrinus sp.
- Platycrinus pocilliformis
- Platycrinus peculiaris
- Platycrinus sp.
- Platycrinus sp.
- Platycrinus sp.
- Platycrinus pileiformis
- Eucladocrinus sp.
- Symbathocrinus sp.
- Coeliocrinus ventricosus
- Cyathocrinus sp.
- Metichthyocrinus clarkensis

BLASTOIDEA
- Schizoblastus sp.

BRACHIOPODA
- Spirifer louisianensis
- Spirifer rowleyi
- Syringothyris sp.
- Brachythyris suborbicularis

GASTROPODA
- Platyceras paralius

FIG. 30.—Faunal list from the blue-gray marl facies, San Andres Canyon, San Andres Mountains.

As yet we have not done extensive work in the San Andres Mountains. The Lake Valley formation has been identified as far north as Sly Gap north of Saline Peak. The Caballero formation is absent here. Alamogordo, Arcente, and Dona Ana members are present but thinly developed. We have followed them south to the area a few miles north of the igneous block in the center of the Organ Mountains.

Baker (1, p. 1679) noted the occurrence of novaculite above Lake Valley limestone and below the Pennsylvanian contact in the northern part of the San Andres Mountains. On the basis of this discovery he has suggested that the Caballos novaculite of the trans-Pecos region of Texas is probably of Lower Mississippian age.

SECTION AT LAKE VALLEY, NEW MEXICO

The section exposed at Lake Valley, New Mexico, on Apache Hill, is normal throughout with the exception that the blue-gray shaly marl

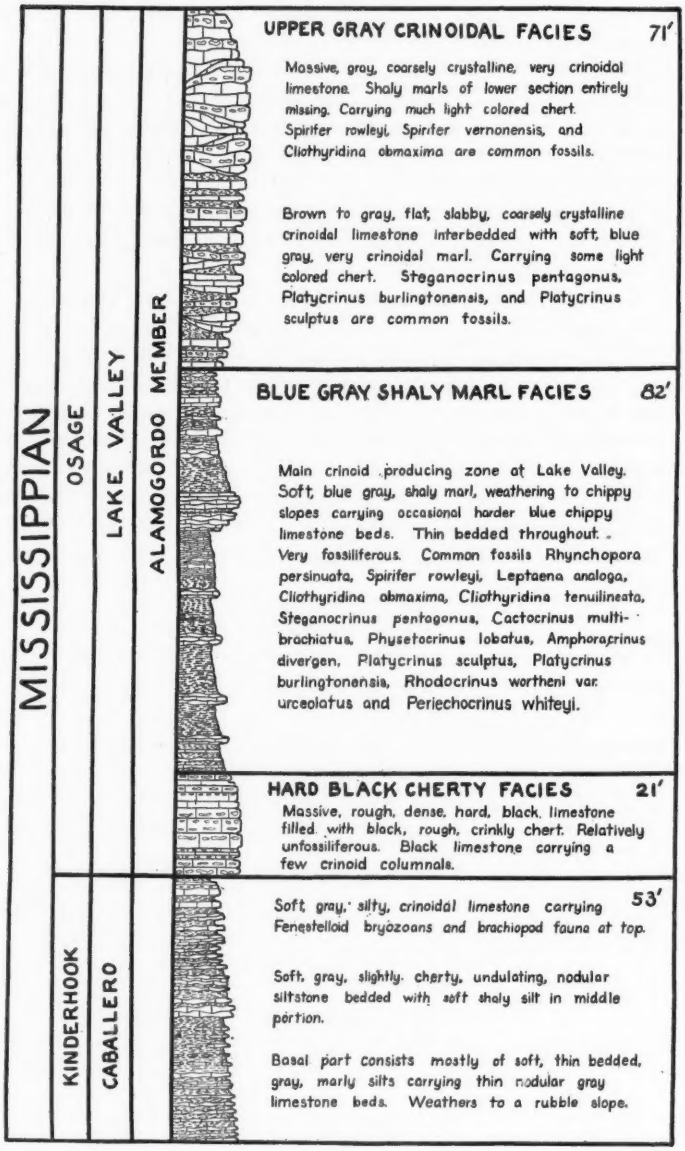
MISSISSIPPIAN
OSAGE
KINDERHOOK
LAKE VALLEY
CABALLERO
ALAMOGORDO MEMBER
UPPER GRAY CRINOIDAL FACIES 71′
Massive, gray, coarsely crystalline, very crinoidal limestone. Shaly marls of lower section entirely missing. Carrying much light colored chert. Spirifer rowleyi, Spirifer vernonensis, and Cliothyridina obmaxima are common fossils.
Brown to gray, flat, slabby, coarsely crystalline crinoidal limestone interbedded with soft, blue gray, very crinoidal marl. Carrying some light colored chert. Steganocrinus pentagonus, Platycrinus burlingtonensis, and Platycrinus sculptus are common fossils.
BLUE GRAY SHALY MARL FACIES 82′
Main crinoid producing zone at Lake Valley. Soft, blue gray, shaly marl, weathering to chippy slopes carrying occasional harder blue chippy limestone beds. Thin bedded throughout. Very fossiliferous. Common fossils Rhynchopora persinuata, Spirifer rowleyi, Leptaena analoga, Cliothyridina obmaxima, Cliothyridina tenuilineata, Steganocrinus pentagonus, Cactocrinus multibrachiatus, Physetocrinus lobatus, Amphoracrinus divergen, Platycrinus sculptus, Platycrinus burlingtonensis, Rhodocrinus wortheni var. urceolatus and Periechocrinus whiteyi.
HARD BLACK CHERTY FACIES 21′
Massive, rough, dense, hard, black, limestone filled with black, rough, crinkly chert. Relatively unfossiliferous. Black limestone carrying a few crinoid columnals.
53′
Soft, gray, silty, crinoidal limestone carrying Fenestelloid bryozoans and brachiopod fauna at top.
Soft, gray, slightly cherty, undulating, nodular siltstone bedded with soft shaly silt in middle portion.
Basal part consists mostly of soft, thin bedded, gray, marly silts carrying thin nodular gray limestone beds. Weathers to a rubble slope.

FIG. 31.—Lake Valley type section, Apache Hill, Lake Valley, New Mexico.

facies of the Alamogordo member is thicker here than in the sections in the Sacramento and San Andres mountains.

The Caballero formation is excellently developed with its typical gray color and nodular bedding. The bedding in this area is a little more regular than it is in the areas farther east. It is not particularly fossiliferous in this area although a careful search will produce a typical Kinderhook fauna.

The *Taonurus* siltstone facies, so characteristic of the Sacramento Mountain area, is missing here. The hard black cherty limestone facies makes its usual persistent scarp.

The most unusual portion of the section is the thick development of the blue-gray shaly marl facies. It is considerably harder in this area, apparently because of a higher lime content. It is in these nodular limestone beds that the famous Lake Valley crinoid fauna occurs. These beds are excellently fossiliferous from the bottom to the top.

The crinoid-bearing marls grade upward into the upper gray crinoidal facies of the Alamogordo member. As in the Sacramento Mountains, the transition is gradual. The lower portion is interbedded with soft marl beds and the crinoid fauna continues right on up into these beds. In the upper portion the beds are more massive and carry considerable chert.

ACKNOWLEDGMENTS

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We wish to express particular appreciation for the large faunal collections which have been made available to us by Frank V. Stevenson of Fort Smith, Arkansas.

Thanks are also extended to M. L. Thompson who has placed the entire Lake Valley collection of the New Mexico School of Mines at our disposal.

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EXPERIMENTS WITH LIGHTS, SHADOWS, AND CONTOURS, AND THE RESULTING SHADOWGRAPHIC CONTOUR MAPS[1]

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ABSTRACT

This paper describes some experiments with the photography of sidelighted folded surfaces made for the purpose of developing a technique that would enable the direct application of lights and shadows to structural contour maps and thereby facilitate their interpretation. For many years the mapping agencies of various governments throughout the world have exerted much effort toward the development of a type of topographic map that would give a better expression of relief than the conventional contour map. Noteworthy progress in this direction has been made by the United States Geological Survey and the Engineering Corps of the United States Army. Both branches appear to agree that the desired ends may be obtained through the application of lights and shadows, but their techniques differ.

The writer of this paper suggests that lights and shadows could be used to good advantage as supplemental aids to the contours of structural maps. The name "shadowgraphic" is proposed and defined to describe this new type of structural map. Certain fundamental rules which now appear desirable in connection with the construction and interpretation of these maps are stated.

The application of lights and shadows to structural contour maps adds the element of unity to the contour framework and furnishes a method by which data on faults and fault patterns may be recorded with proper emphasis. Five examples of published maps, first in their original published form and then after shadowgraphic treatment, conclude the paper.

INTRODUCTION

Since the dawn of recorded history, man, in making maps, has been confronted with the problem of recording the data of a three-dimensional subject on an essentially two-dimensional plane. Early in the struggle and due to the crude media available, maps or models actually had the third dimension indicated in the carved wood, stone, or clay representations of topography. An interesting example of the transitional phase from crude media to the more refined is found in the maps on skin with outstanding topographic features represented by carved wooden blocks secured in proper place on the map surface by thongs.[3] Evidence concerning the work of the ancient Egyptian, Greek, and Roman cartographers indicates that they were most concerned with the accurate recording of the ordinary two dimensions of the map and the larger aspects of the problems of cartography, and although their treatment of the problem of representation of relief is obscure it seems improbable that they ignored it. The Incas of Peru are given credit for having produced the first relief maps of which there

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[3] Col. Harry H. Blee, "Third Dimensional Maps," *The Military Engineer*, Vol. XXXII, No. 183 (May–June, 1940).

remains a record. This was at the time of the 9th Inca who died 1191 A.D.[4] As the cartographic arts and sciences grew, a series of symbols came into general use many of which have persisted down to the present time. The old problem of indicating relief still remained and became even more acute because of more exacting requirements of military uses and the more refined media employed in map making. The earliest use of contours as we know them today is attributed to M.S. Cruquius in his charting of the Merewede River in Holland during the year 1728.[5] In the year 1788 Muller refined and systematized the crude hatchings found on early maps into a system of hachures to enable the expression of relief in much greater detail. His system and its modified forms were destined to survive more than a century. Just eleven years later J. G. Lehmann, who directed a survey of Saxony (1780–1806), published his *Theorie der Bergzeichnung* in which he proposed the use of hachures in conjunction with contour lines for the purpose of indicating relief. Contemporaneously with this progress others were experimenting with the use of graduated tints on maps to aid their relief expression. It was with this background that Laplace in 1816, suggested the use of contours alone to represent topographic relief. This outstanding advance in the science of cartography attained the desired objective of accurately depicting the topographic relief but failed to convey the much desired complete impression of relief in all of its details. The various mapping agencies of governments throughout the world have realized this shortcoming of contour maps and have continued their search for the perfect combination of techniques. Contour maps, representing the vital engineering data, have formed the base to which other modes of expression such as hachures, colors, and shading have been added. The shaded French military maps which used a dual source of light are reported to be particularly effective in representing areas of low relief, but the system is said to fail when applied to mountainous terrane. Early in the history of the United States Geological Survey an effort was made to improve the relief expression of its published topographic maps. Monograph X[6] is accompanied by an excellent lithographed contour map of Lake Lahontan and vicinity on which is noted "Mountain Shading by J. W. Hays." Monograph I[7] appeared five years later, and the general topographic map accompanying this outstanding contribution to the science of geology also shows the application of lights and shadows to

[4] *Ency. Brit.*, Vol. 14, pp. 837, Ed. 1940.

[5] *Ency. Brit.*, Vol. 14, pp. 835, Ed. 1940.

[6] I. C. Russell, "Lake Lahontan," *U. S. Geol. Survey Monograph X* (1885).

[7] G. K. Gilbert, "Lake Bonneville," *U. S. Geol. Survey Monograph I* (1890).

the contoured areas to emphasize the expression of relief. As indicated by Beaman,[8] these early efforts were soon abandoned because of excessive lithographic costs, and it was not until 1921, when new developments in photolithography made possible economical reproductions of the most delicate shades, that the United States Geological Survey again turned its active attention to the problem, and then its "shaded topographic" maps were developed in friendly competition with the "pictorial relief" maps of the Engineering Corps of the United States Army. It appears that the "shaded topographic" maps were the result of direct application of lights and shadows to the contoured area whereas the "pictorial relief" maps were provided with these from actual photographs of relief models of each area mapped. The first product of this new effort by the United States Geological Survey was the Monument Springs (Texas) Quadrangle (1921), which map brought its makers a wave of commendation. This work continued through 1925 but instead of the brown shading applied to the first map a more effective "shadow gray" was substituted on the thirteen succeeding ones which covered various areas in the Appalachian region. Lights and shadows applied to these maps were those which, with some modification, would be observed were the area bathed by the light of a 4 P. M. sun on a late summer day.

GEOLOGICAL STRUCTURAL MAPS

The first published contour map designed to show geological structure made its appearance during 1870.[9] During the seventy years that have passed little attention has been given and small progress has been made toward facilitating their interpretation. More and more complicated structural situations have been mapped and newly developed instruments and data determining procedures threaten to swamp our maps with a flood of informative data that our now antiquated methods of recording will no longer accommodate. This static condition in the technique of recording structural data may be traced to the fact that most geologists are well trained in the construction and interpretation of contour maps, and in this respect are much better prepared than many who are called upon to interpret topographic maps. The magnitude of the task and, in some cases, time and economic factors have precluded any procedure other than the quickest and most economical, even though inadequate, recording of observed data. As the economic application of structural mapping progresses and the reconnaissance phase is completed it would appear logical to

[8] W. M. Beaman, "Part 'E'," *U. S. Geol. Survey Bulletin 788* (1929).

[9] B. S. Lyman, "General Report on the Punjab Oil Lands" (Lahore).

expect a more refined type of map to replace the earlier efforts. These maps should present the structural features as units, in which the most minute details and the larger regional aspects are equally well represented. With maps such as these, one might expect the geologist to progress beyond his present realm of structural interpretation.

Because of the specialized training required in the interpretation of geological structural maps, many of us have good reasons to doubt the effectiveness of these in conveying their full meaning to members of commissions and juries, executives, and students, to list only a few of the groups of the public at large which strive to understand our work. This barrier to complete appreciation of our maps must be overcome before we can hope to see the products of our efforts serve their full usefulness to society.

PHOTOGRAPH OF MODELED STRUCTURAL MAP

The writer first became interested in the possibilities of increased expression of our structural maps through the application of lights and shadows to the contoured surface in the year 1932. During that year he constructed and later photographed a wooden model of a structural contour map. One of these photographs, taken from a vertical position, conveyed in a remarkable degree the impression of the structural relief indicated by the contours. A closer examination of the photographic print through a hand lens revealed an even more emphatic impression of the same and disclosed that it was the faithfully recorded lights, highlights, and shadows cast by the modeled surface which, in this case, was the contour plane. The improved emphasis of the impression of relief expression when viewed with but one eye may be due to the elimination of the range-finding abilities of the eyes when two are used. This ability of the eyes to convey the truthful impression that the surface of the photographic print was flat created a certain amount of conflict with the impressions furnished by the lights, highlights, and shadows indicating the surface to be irregular and folded. The use of but one eye eliminated this early confusion and a little experience made this procedure as unnecessary as it would be for comprehending any other type of photograph.

SHADOWGRAPHIC STRUCTURAL MAP

It is obvious that construction of models of geological structure, and the photography of their lighting effects for the purpose of capturing the impression of relief is, in most cases, impractical. Recently the writer has spent considerable time in investigating the possibilities of direct application of lights, highlights, and shadows to struc-

tural maps with the hope that some of their present limitations might be overcome. The early results of this work and the interest that has developed in them, both by geologists and laymen, appear to warrant further efforts in this direction.

A name for this type of map is needed but because it deals with geological structure, the tentative designation of "shaded topographic" to the United States Geological Survey maps (which name does not adequately designate even the topographic map) and the "pictorial relief" designation by the Engineering Corps are inapplicable. It is here proposed, therefore, that the name "shadowgraphic" be applied to this type of structural map—the word being derived from the combination of the words "shadow" and "graphic," resulting in a descriptive term conveying the thought of a shadow-effect contour map. The shadowgraphic map may be defined as a contoured map showing geological structure to which have been added lights, highlights, and shadows that, with some modification, would be observed if the contour plane, composed of a light-reflecting substance, were modeled as indicated by the contours and illuminated by a light of proper location, elevation, quality, and intensity.

EXPERIMENTAL PROCEDURE

The writer accepted the photographic reproduction of lights, highlights, and shadows, and the imperceptible gradation of one into the other as an objective to be attained in the construction of shadowgraphic maps. White satin was used as the contour plane and was thrown into folds to represent structural deformation similar to that encountered in our structural mapping. This folded surface was then lighted from the side and photographed, and the lights, highlights, and shadows recorded were studied. The photograph of one of these folded surfaces is shown in Figure 1 and, although the quantitative data concerning the actual elevations of points on the folded surface can only be estimated, there is abundant evidence recorded by the lights, highlights, and shadows concerning the other characteristics of the folded surface. Measurements of elevations were made to establish control points, and these, in conjunction with a study of the photograph, made it possible to contour the folded surface as shown in Figure 2. These contours record the engineering facts involved in representing the folded surface, but the feeling of flatness has replaced the inescapable impression of relief conveyed by Figure 1. Figure 3 combines the photographically recorded lights and shadows of Figure 1 with the contours of Figure 2, and here, for the first time, the engineering data are combined with the photograph of the contour plane

FIG. 1.—Photograph of sidelighted folded surface.

FIG. 2.—Folded surface of Figure 1 shown by contours.

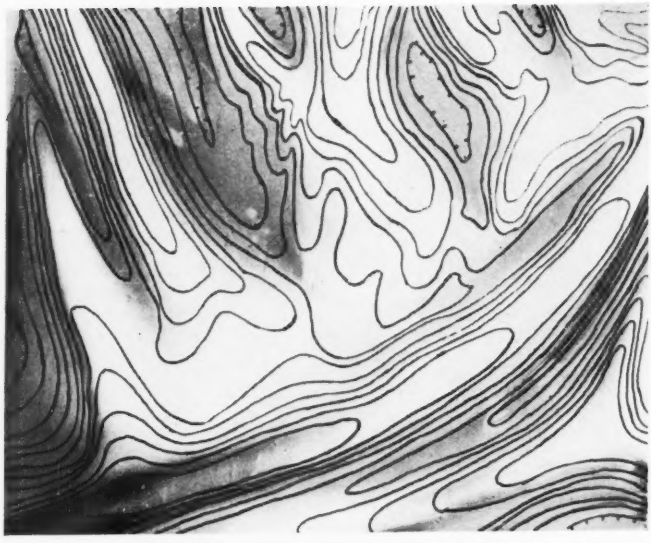

FIG. 3.—Combination of photographed lighting effects of Figure 1 and contours of Figure 2.

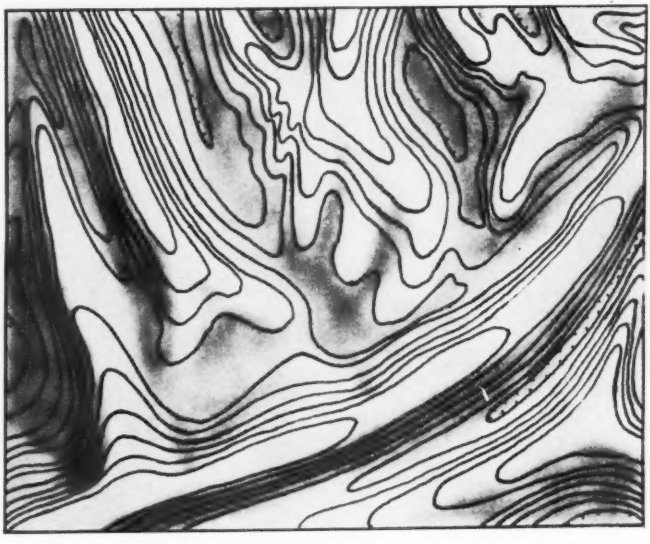

FIG. 4.—Shadowgraphic treatment of Figure 2.

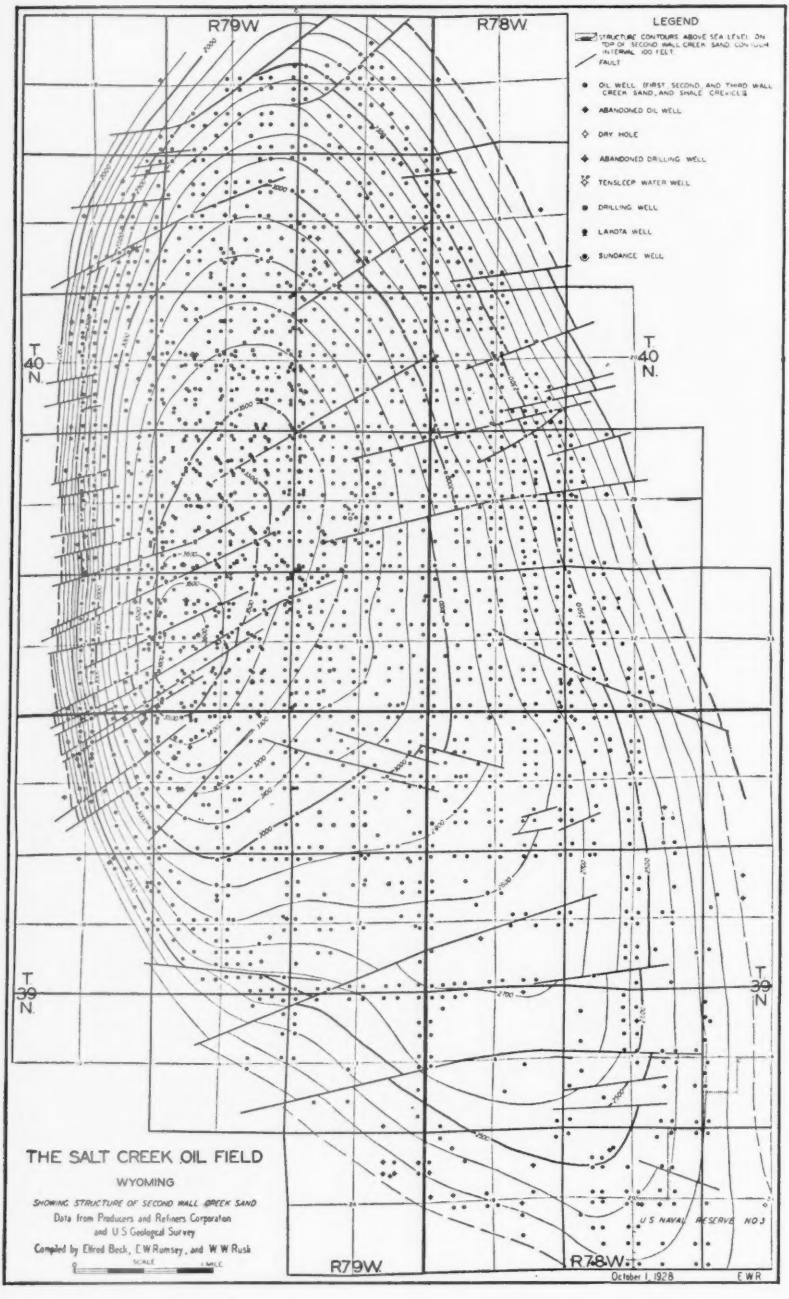
R79W
R78W
LEGEND
STRUCTURE CONTOURS ABOVE SEA LEVEL ON TOP OF SECOND WALL CREEK SAND CONTOUR INTERVAL 100 FEET
FAULT
OIL WELL (FIRST, SECOND, AND THIRD WALL CREEK SAND, AND SHALE CREEK)
ABANDONED OIL WELL
DRY HOLE
ABANDONED DRILLING WELL
TENSLEEP WATER WELL
DRILLING WELL
LAKOTA WELL
SUNDANCE WELL
T 40 N.
T 39 N.
THE SALT CREEK OIL FIELD
WYOMING
SHOWING STRUCTURE OF SECOND WALL CREEK SAND
Data from Producers and Refiners Corporation
and U S Geological Survey
Compiled by Elfred Beck, E W Rumsey, and W W Rusk
SCALE
1 MILE
U S NAVAL RESERVE NO 3
October 1, 1928
E W R

FIG. 5.—Salt Creek oil field, Natrona County, Wyoming, by Elfred Beck and others. From *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929), Fig. 1, p. 592.

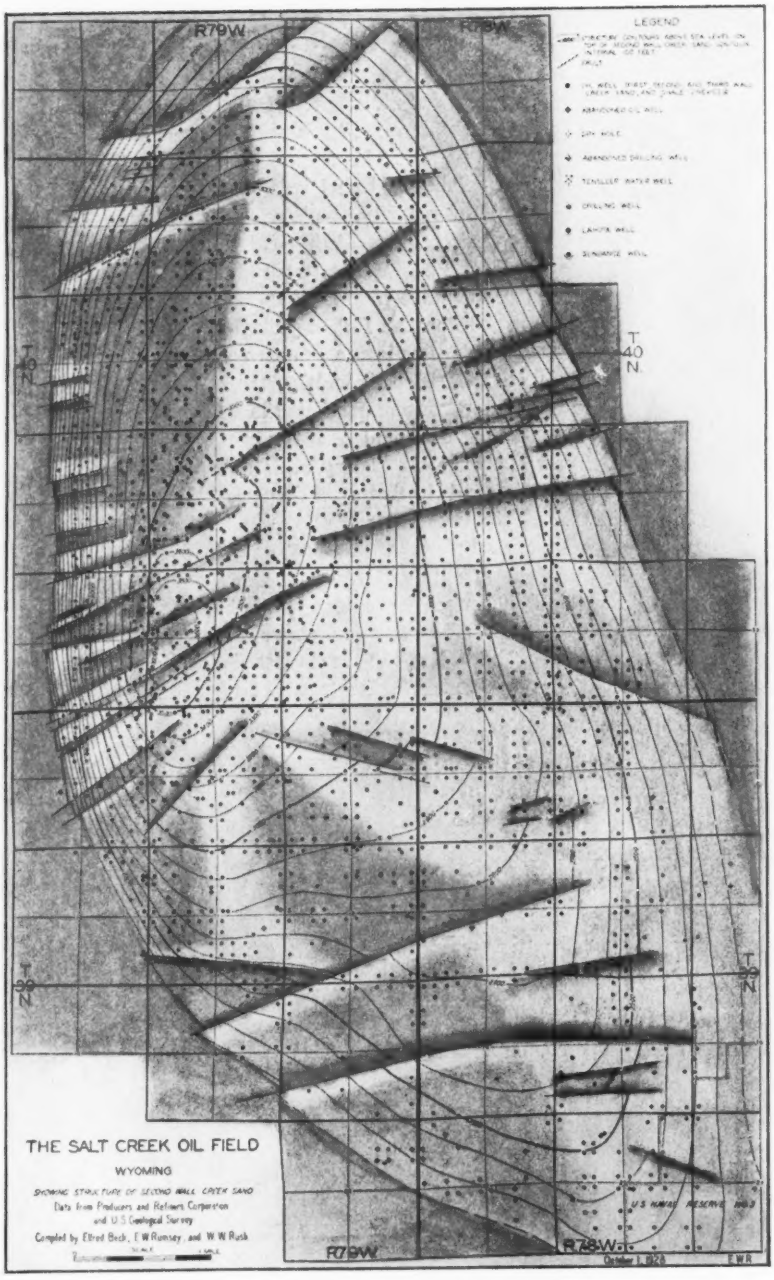

FIG. 6.—Figure 5 after shadowgraphic treatment.

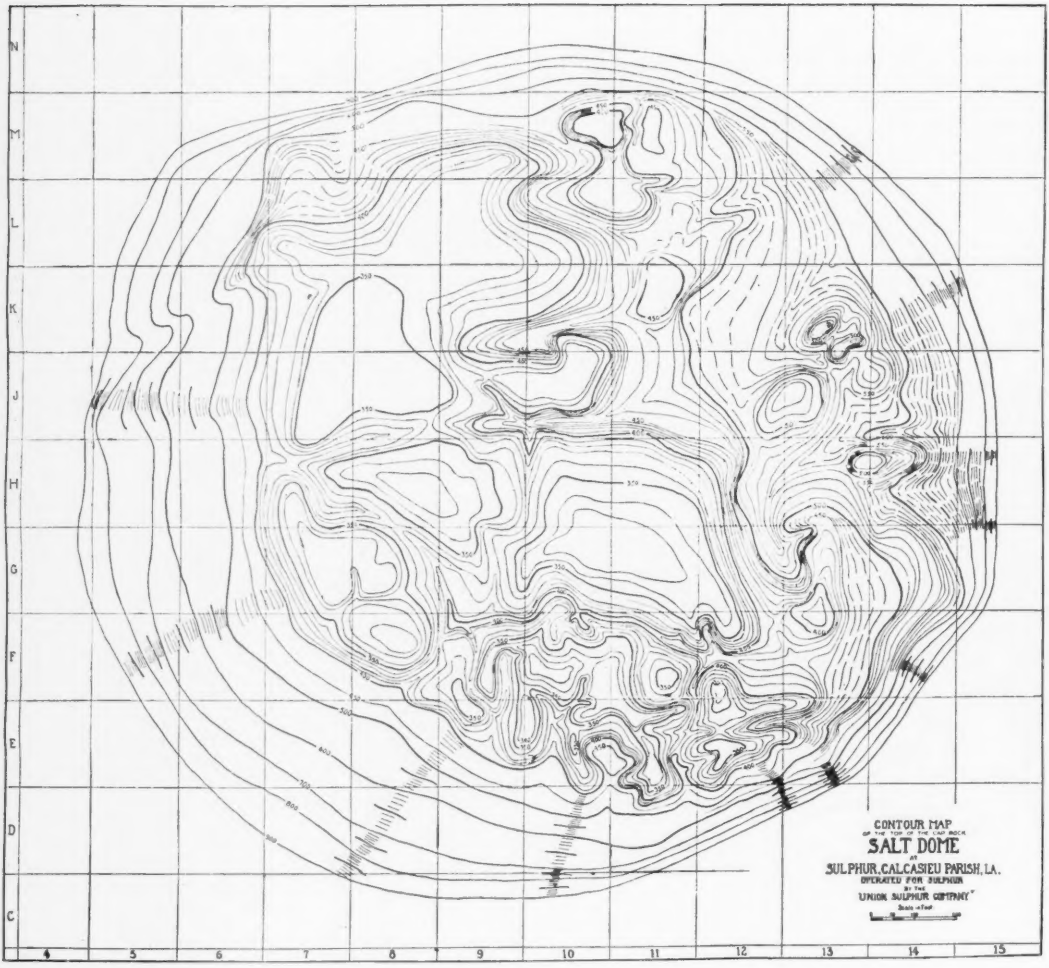

FIG. 7.—Sulphur salt dome, Calcasieu Parish, Louisiana, by P. K. Kelley. From *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 3 (May-June, 1925), Fig. 3, opp. p. 483.

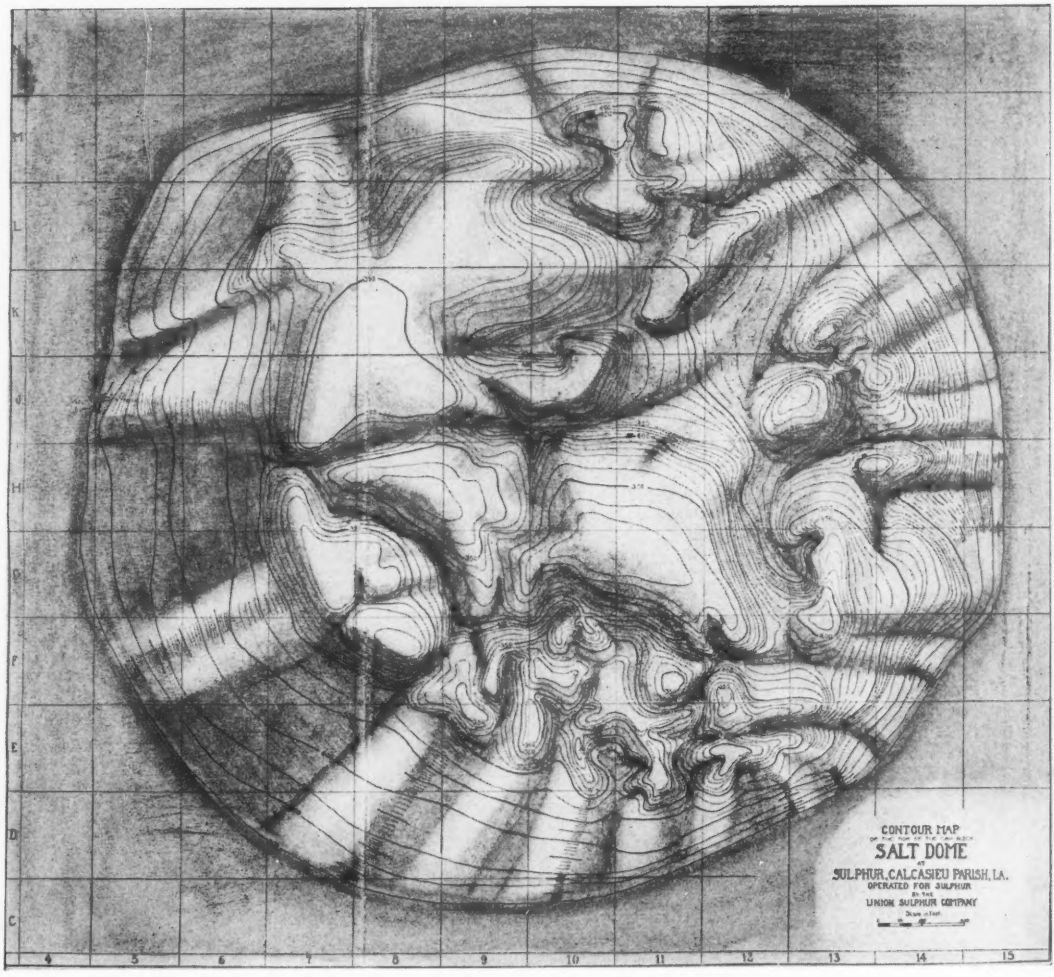

FIG. 8.—Figure 7 after shadowgraphic treatment.

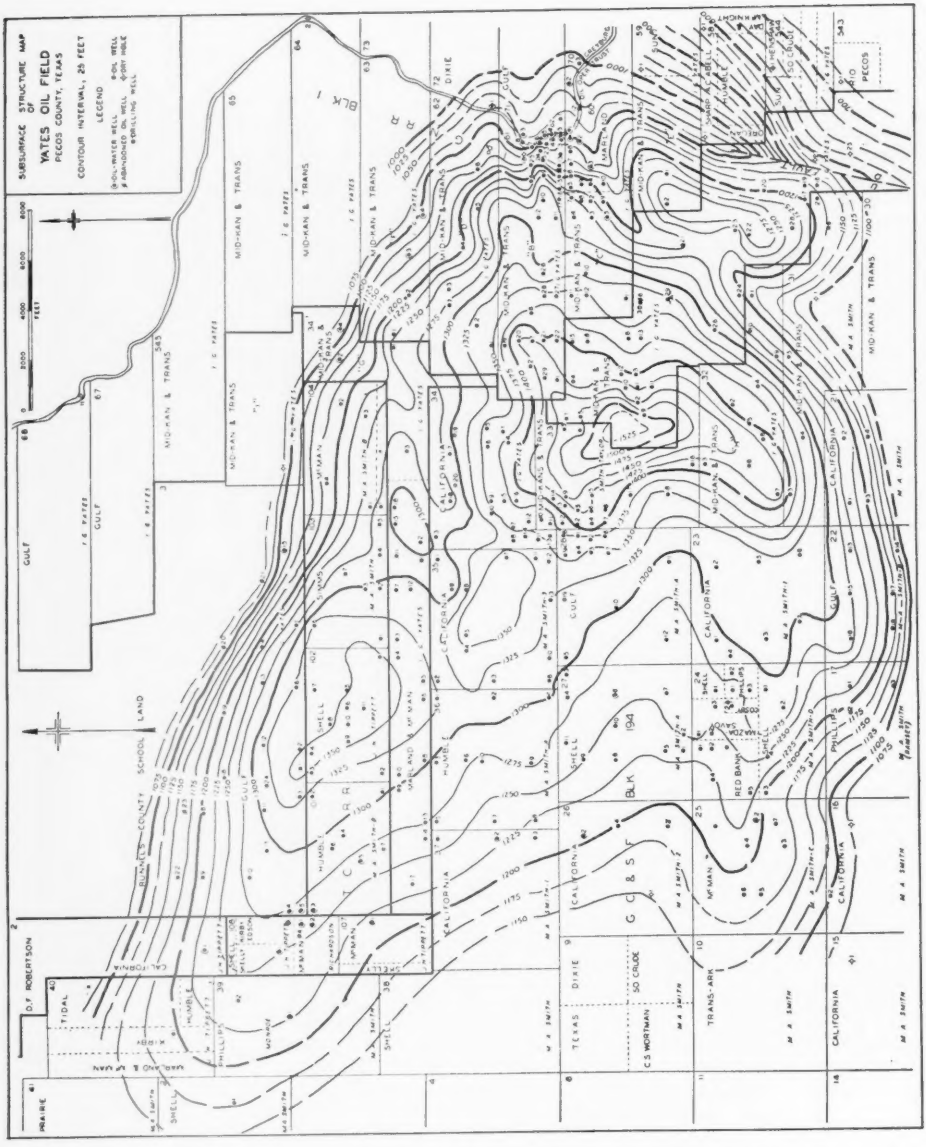

FIG. 9.—Subsurface map of Yates oil field, Pecos County, Texas, by Ray V. Hennen and R. J. Metcalf. From *Bull. Amer. Assoc. Petrol. Geol.* (December, 1930), Fig. 4, p. 1526; *Oklahoma Geol. Survey Bull. 40*, Vol. II (1930), p. 454.

FIG. 10.—Figure 9 after shadowgraphic treatment.

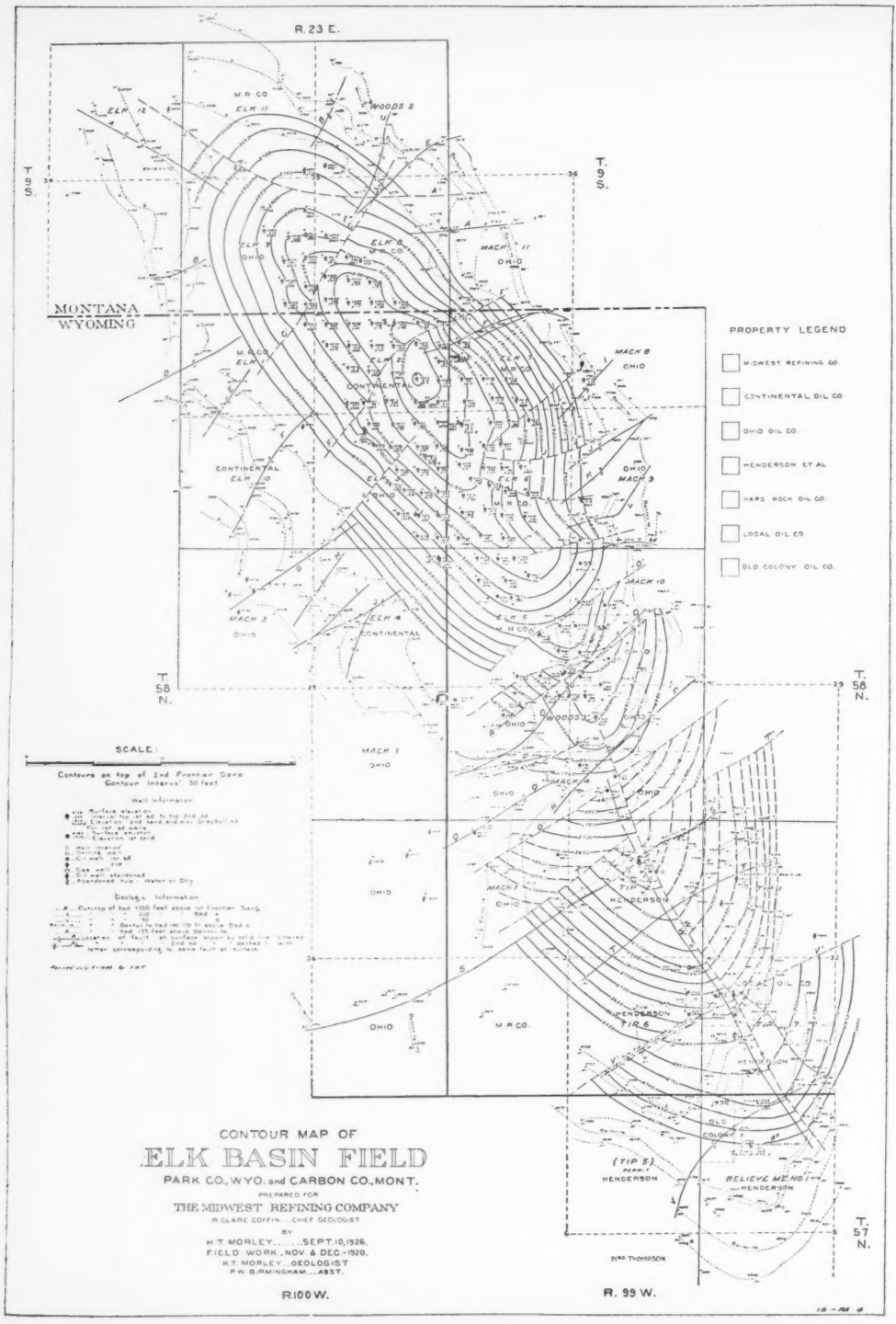

FIG. 11.—Map of Elk Basin field, by H. T. Morley and others From "Elk Basin Oil and Gas Field, Park County, Wyoming, and Carbon County, Montana," by John G. Bartram, *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929), Pl. 1, opp. p. 580.

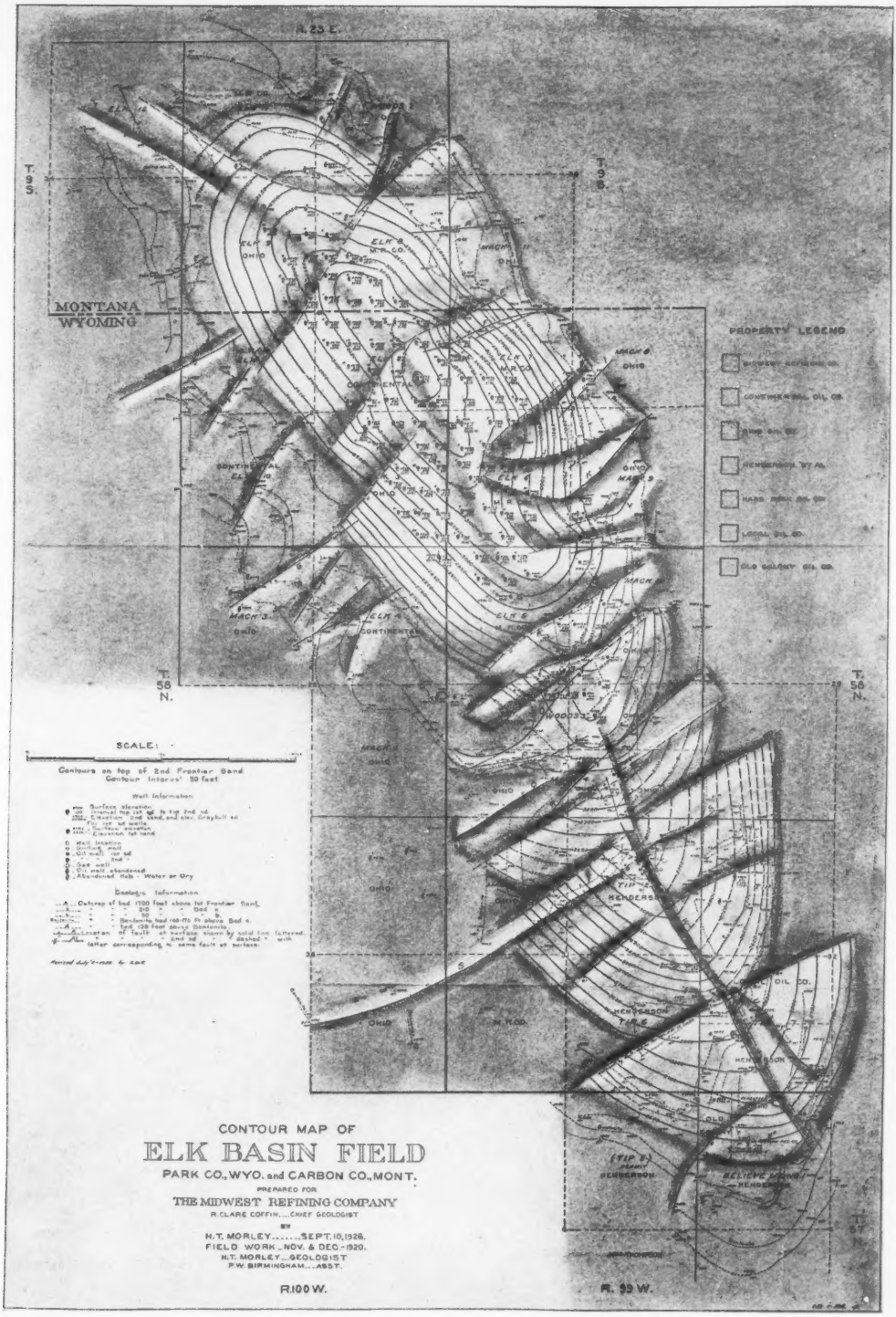

FIG. 12.—Figure 11 after shadowgraphic treatment.

FIG. 13.—Subsurface map of Conroe field, Montgomery County, Texas. From *An Introduction to Gulf Coast Oil Fields*, prepared for the 1941 convention of the American Association of Petroleum Geologists, by the Houston Geological Society (April, 1941).

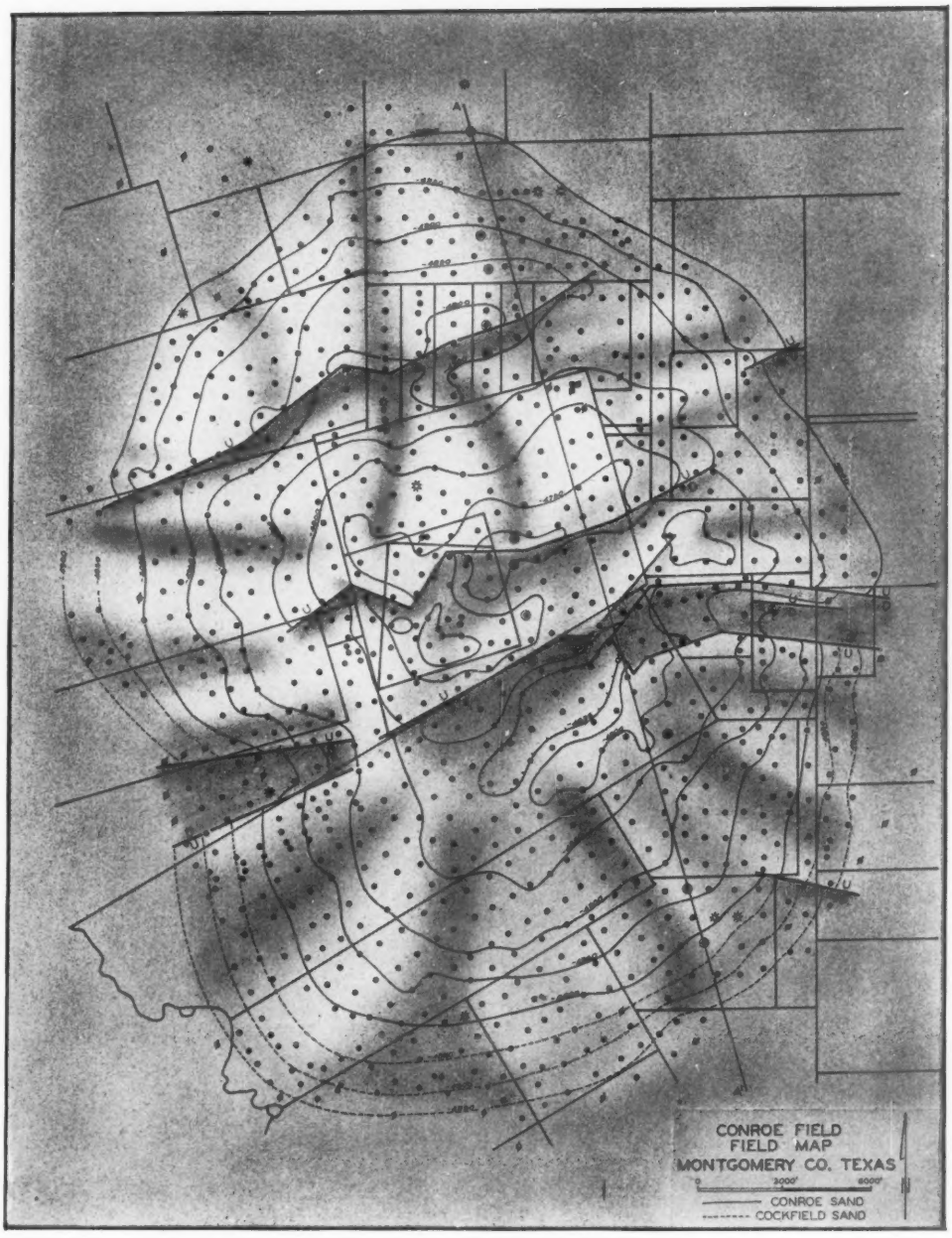

FIG. 14.—Figure 13 after shadowgraphic treatment.

to produce a map which possesses all of the essential engineering characteristics along with the added vital ones of instant legibility and comprehension. Figure 4 is a shadowgraphic map of the same area with hand-applied lights, highlights, and shadows added to the contours of Figure 2. It is an entirely synthetic product which combines lights, highlights, and shadows with contours to give the impression of relief, but is in no way dependent on the photography of models to attain this end. With the need for models eliminated, the last obstruction to wider experimentation with structural maps was overcome. The encouragement and inspiration derived from these earlier attempts led to the attack of more complicated structural maps in an effort to develop the required mastery of technique and to test the wide variety of available media. Hundreds of published and unpublished maps experienced their first contact with applied lights and shadows and the writer feels that, for the first time, they approach the full expression of structural facts they were intended to convey. Figures 5 to 14 show some of these more complicated structural maps —(1) the map as originally published, and (2) the same map after shadowgraphic treatment. These are presented here not with the thought that they represent, to any great extent, a well developed technique, for many of them are the results of very early efforts, but rather that they may serve to illustrate the improved unity, impact, and readability of the maps thus treated.

BASIC RULES CONTROLLING CONSTRUCTION

Experience to date indicates that there are several important rules which should be observed.

Rule 1.—Nothing of the original map may be obliterated or seriously obscured. If the map is to retain all of its engineering characteristics, it is essential that the applied film be of transparent or extremely thin color.

Rule 2.—For optical or psychological reasons the light source must be from a northerly direction—either northwest, north or northeast. The United States Geological Survey and the Engineering Corps appear to have limited themselves to a northwest direction for the light source in the construction of their "shaded topographic" and "pictorial relief" maps respectively. Further experiments and experience may indicate that similar limitations should be applied to shadowgraphic maps, but for the present the freedom of selection of direction within the wider limits appears more desirable. The most effective results are obtained when the light source is at an approximate right angle to the predominating structural axis; thus the wider limits men-

tioned above make it possible to illuminate effectively all possible structural grains.

Rule 3.—The elevation of the assumed source of light has by experience been found most effective at approximately thirty degrees above the plane of the map surface. In this connection, however, it should be pointed out that an arbitrary rule has been applied to the "shaded topographic" maps and to the shadowgraphic maps which limits the deeply shaded areas solely to the surfaces sloping away from the light source. In no case is a shadow allowed to transgress a stream course on the topographic map or a syncline on a structural map, even though the conception of the modeled contour plane would call for these shadows, under certain topographical and structural conditions, to extend considerably beyond these limits. The pictorial relief maps, however, having photographically recorded lights and shadows of actual relief models, show, without limitation, the shadows cast by these models.

Rule 4.—The downthrown side of a normal fault is always shaded. When dealing with faults with the downthrown side away from the direction of the light source this is entirely regular and presents no problem, but it is in connection with the fault having a downthrow toward the direction of the light source that the rule is in conflict with what would be the observed lighting effects. In an effort to compromise this difference and still retain a valuable principle which makes possible for the first time the representation of faults with the emphasis they deserve, shadows are softened at these points of conflict.

Rule 5.—Shadowgraphic maps are based on the representation of the contour plane and therefore to recover it from the realm of the imagination where it is placed by the conventional contour map it is present on the surface of the map in the form of a thin film of pigment. The lighting effects shown by the variation of intensity of reflected light are those which would be expected from a highly polished contour plane as it is molded to and always completely controlled by the skeleton of contours.

ACKNOWLEDGMENTS

This paper would be incomplete without an expression of appreciation of the valuable assistance that has been so freely given by members of our profession, by those of related professions, and by the laymen who have had but little contact with maps. In attempting to overcome the psychological problems involved, the reactions of those individuals who have groped for understanding have been as valuable as the reactions of those who, not trusting their sense of vision, touched

the maps to assure themselves that the surface was not folded. The progress that has been made is largely the result of the constructive criticisms, suggestions, and encouragement furnished by many individuals over a long period of time.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 12 (DECEMBER, 1941), PP. 2170-2180, 4 FIGS., 1 PL.

DEPOSITION OF FREE OIL BY SEDIMENTS SETTLING IN SEA WATER[1]

O. A. POIRIER[2] AND GEORGE A. THIEL[3]
Tulsa, Oklahoma, and Minneapolis, Minnesota

ABSTRACT

A new approach to the problem of the origin of oil and source beds of petroleum is made by an experimental study of the deposition of oil as a sediment. Oil dispersed in a mixture of fine-grained sediment and sea water will settle and be trapped on the bottom by the sediment. Experimental observations are made on the oil-settling characteristics of a series of 10 different sediments, which represent a wide range of possible source beds of petroleum. Comparative results of the volume of oil that one gram of each sediment can completely carry down and trap in an oil sediment-sea water mixture are tabulated. This volume of oil deposited varies considerably throughout the series of sediments studied, and is generally found to be inversely proportional to the size of the mineral grains. Microscopic examination of the oil sediment shows that the oil is carried down by the weight of mineral grains adhering to the globules.

INTRODUCTION

The problem of the origin of petroleum has been discussed for many years and although much pertinent information and many valuable ideas have been contributed, there still does not seem to be a single theory acceptable to petroleum geologists. This paper shows how oil might be carried down by settling sediments, if any were present in liquid form at the time of deposition of the enclosing sediments. Comparative results are tabulated to show the amount of free oil that a given sediment, dispersed in sea water, can carry down and hold under water.

MATERIALS AND METHODS

Any attempt to duplicate the environments in a marine basin of sedimentation involves numerous variables such as (1) the composition of sea water, (2) temperature, (3) size of clastic fragments, (4) mineral composition of sediments, (5) specific gravity of particles, (6) viscosity of the sea water, and (7) nature of oil particles. In this study only three factors were considered and controlled, namely, (1) the kind of sediments, (2) the size of sedimentary particles, and (3) the amount of oil.

KIND OF SEDIMENTS

The sediments were chosen to represent a wide range of possible source beds, so that the results obtained would be applicable to field occurrences.

[1] Manuscript received, May 27, 1941. Part of a thesis for the degree of Master of Science at the University of Minnesota, June, 1940.

[2] Seismograph Service Corporation.

[3] Department of Geology, University of Minnesota.

1. *Shale.*—Decorah shale of Ordovician age from southeastern Minnesota. The formation is a thin-bedded, light, blue-green shale of fair consolidation. Textural analyses indicate that more than 70 per cent of the material is finer than 1/100 millimeter. Microscopic and X-ray analyses show that it is mainly fine-grained quartz and orthoclase. The feldspar is both authigenic and detrital.

2. *Silt.*—A siliceous and feldspathic, clayey silt from the Blue Earth formation near Mankato, Minnesota. Approximately 60 per cent of the clay size. The fraction finer than 1/10,000 millimeter is dominantly mica.

3. *Marl.*—A fresh-water lake sediment containing 85 per cent soluble carbonate, from Keller Lake near St. Paul, Minnesota. The material is unconsolidated, of light gray color and uniformly fine-grained texture.

4. *Bentonite.*—White, homogeneous, fine-grained bentonitic clay from near Upton, Wyoming. X-ray analyses indicate that the clay is high in montmorillonite, with small quantities of feldspar, quartz, and carbonate.

5. *Diatomaceous earth.*—A well consolidated, fine-grained, siliceous sediment from California. The material is a hydrous or opaline form of silica with varying amounts of organic matter and inorganic impurities such as sand, crystalline silica, clay, volcanic ash. It is of organic origin, consisting of fossil remains of microscopic aquatic plants.

6. *Oil shale.*—A sample from the Mahogony Ledge of the Colorado shale, supplied by the Colorado School of Mines. After crushing, the sample was treated with carbon tetrachloride solvent to remove all liquid oil. Microscopic examination showed that the rock contained much organic material which was not removed by the solvent.

7. *Humus soil.*—A soil of high organic content, dark brown in color, and of low specific gravity when dry. Dispersion and decanting after settling two minutes removed 98 per cent of the sediment.

8. *Calcareous silt.*—A synthetic sediment composed of 50 per cent fine lacustrine clay and 50 per cent marl such as described under Sediment No. 3.

9. *Calcareous shale.*—A mixture of equal parts of marl and Decorah shale.

10. *Silty sand.*—A mixture of equal parts of St. Peter sandstone and Blue Earth silt.

11. *Kaolin.*—A light, greenish gray, residual clay derived from the weathering of the Morton granite gneiss at Morton, Minnesota. X-ray analyses show that the clay is predominantly kaolinite.

SALINITY OF WATER

A synthetic sea water was prepared, based on the table of average composition of sea water after Dittmar.

Salts (3.44 per cent by weight) added to distilled water; rarer salts omitted.

	Per Cent
$NaCl$	78.20
$MgCl_2$	10.96*
$MgSO_4$	4.76*
$CaSO_4$	3.71*
K_2SO_4	2.48
	100.00

* Corrections were made for weight calculations of hydrous salts.

KIND OF OIL

Oily residues such as may occur in sediments would be difficult to duplicate. Therefore, a Mid-Continent crude oil of 32.7°Bé. at 60°F. was used for the experiments.

METHODS

The sediments were crushed and screened. Two sizes, A ($\frac{1}{4}$-$\frac{1}{8}$ mm.) and B (less than $\frac{1}{8}$ mm.), were subjected to the same treatment in a soil-dispersion machine which was used to deflocculate the sediments and to mix the oil with the sea water and sediments. Sedimentation was allowed to take place in glass tubes 50 centimeters in length and 28 millimeters in diameter. They were placed in a wooden rack that held them in a vertical position. The open ends of the tubes were sealed with gum-rubber stoppers. The stoppers at the upper end were perforated to allow air to pass as the stoppers were inserted.

Since the number of particles in a suspension influences the rate of settling, high concentrations of sediment were avoided. Where the amount of sediment is great, there is interference between particles, and vertical currents are established which tend to carry oil upward toward the surface of the water. Furthermore, a high silt concentration alters the viscosity and density of the fluid so that in very muddy waters the rate of settling is retarded. Rubey[4] states that this factor is negligible for concentration less than 1 or 2 per cent. Thus, in all of the experiments conducted by the writers only one gram of dry pulverized sediment was added to 200 cubic centimeters of sea water.

Preliminary experimentation demonstrated that the amount of oil carried down by any sediment is directly proportional to the time of dispersion, which in turn means a similar direct decrease in size of grain of sediment and in size of oil globules. Thus, by tabulating the amount

[4] W. W. Rubey, "Lithologic Studies of Fine-Grained Upper Cretaceous Sedimentary Rocks of the Black Hills Region," *U. S. Geol. Survey Prof. Paper 165-A* (1931).

of oil completely carried down at the end of 5 minutes, 15 minutes, and 30 minutes, total deflocculating periods, respectively, it is possible to use these three points to establish a curve for the oil-settling capacity of each sediment.

TABLE I

SAMPLE RECORD USED TO TABULATE LABORATORY RESULTS

CALCAREOUS SILT NO. 8

Size A
($\frac{1}{4}$–$\frac{1}{8}$ mm.)

Deflocculating Time in Minutes

5			15			30		
Tube	*Cc. Oil*	*Settled**	*Tube*	*Cc. Oil*	*Settled**	*Tube*	*Cc. Oil*	*Settled**
2	0.75	O	2	1.20	O	2	2.00	O
4	0.25	X	4	0.75	X	4	1.00	X
6	0.50	X	6	1.00	O	6	1.50	O
	0.50			0.75			1.00	

Size B
($-\frac{1}{8}$ mm.)

Deflocculating Time in Minutes

5			15			30		
Tube	*Cc. Oil*	*Settled**	*Tube*	*Cc. Oil*	*Settled**	*Tube*	*Cc. Oil*	*Settled**
3	0.50	X	3	1.20	O	3	2.00	O
5	1.50	O	5	1.50	O	5	1.50	O
7	1.00	O	7	1.00	O	7	1.00	X
8	0.75	X	8	0.85	X	8	1.25	X
	0.75			0.85			1.25	

* O, incomplete oil settling.
X complete oil settling.

Figure 1 illustrates the effect of prolonged dispersion on the oil-settling capacity of a sediment. Notice the relative amounts of excess oil on the surfaces of tubes 4 and 5, and the increased thickness of bottom sediment in tubes 5 and 6.

Table I shows the method used to tabulate the laboratory results. Fine-grained sediments less than $\frac{1}{8}$ millimeter (Size B) are able to carry down a greater amount of oil than the coarser sediments (Size A).

The index employed to determine the "saturation" point proved satisfactory inasmuch as it is of comparative value for all sediments. However, it does not give the absolute capacity of any sediment. Humus soil high in plant fibers is incapable of carrying down all of

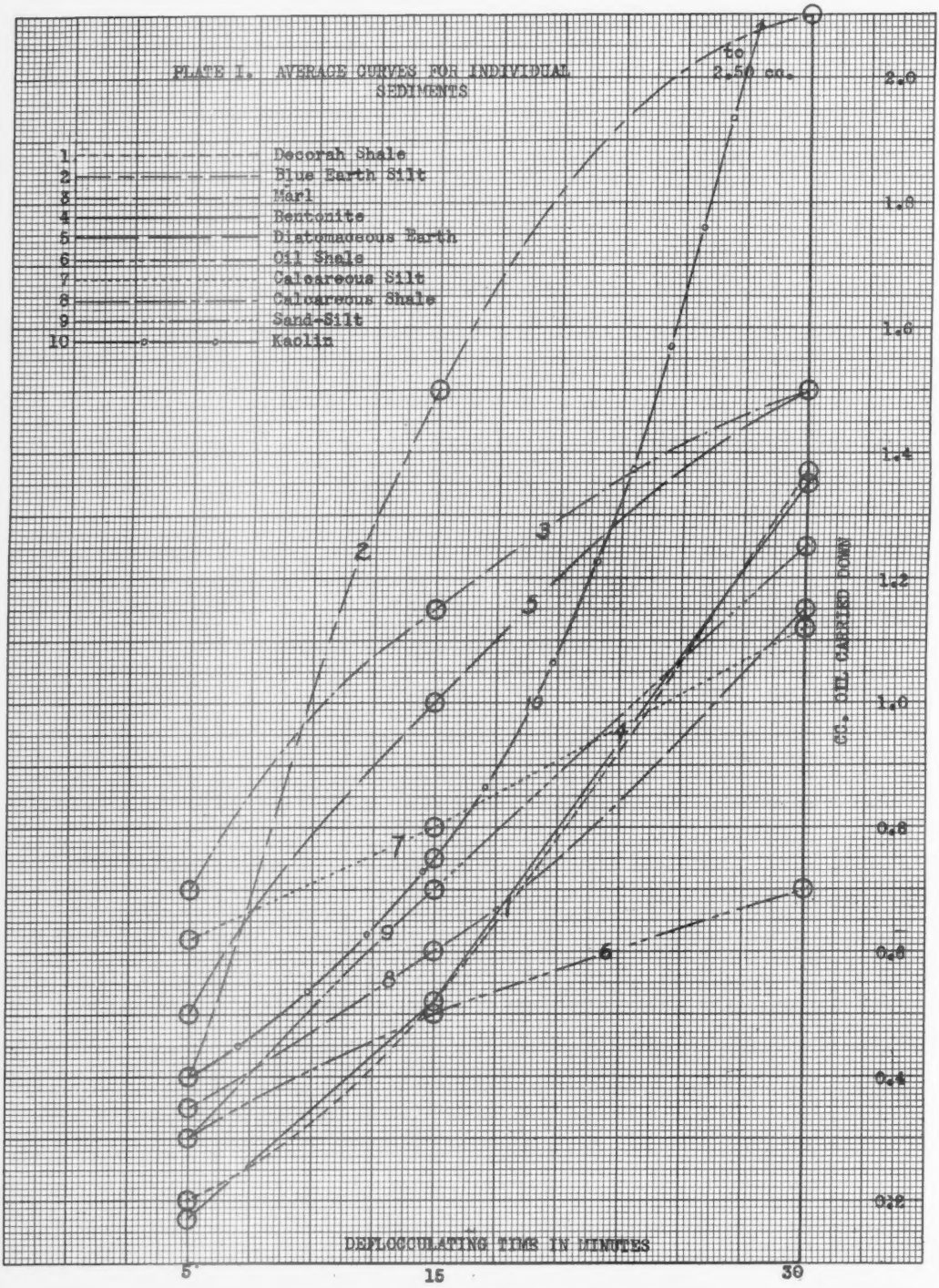

PLATE I.—Average curves for individual sediments.

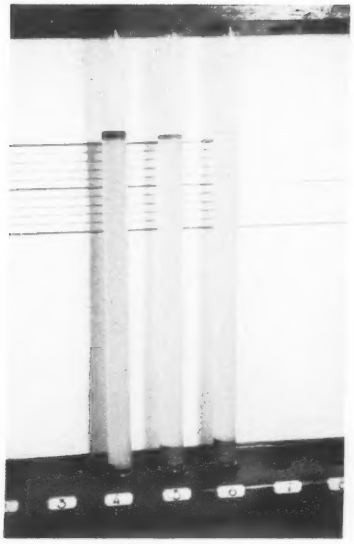

FIG. 1.—Sedimentation tubes showing effect of prolonged dispersion on oil-settling capacity of a sediment. Three tubes contain equal amounts (1 gram) of Blue Earth silt, and equal amounts (2.50 cc.) of oil. Material in tube at left was dispersed for 5 minutes, in middle tube 15 minutes, and in tube at right 30 minutes. All the oil was carried down and held down in tube at right.

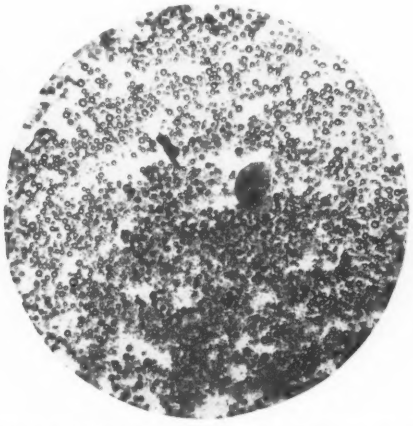

FIG. 2.—Photomicrograph of oil globules and diatomaceous earth from bottom of sedimentation tube. Mag. ×50.

FIG. 3.—Photomicrograph of humus earth fragments surrounded by oil. Mag. ×50.

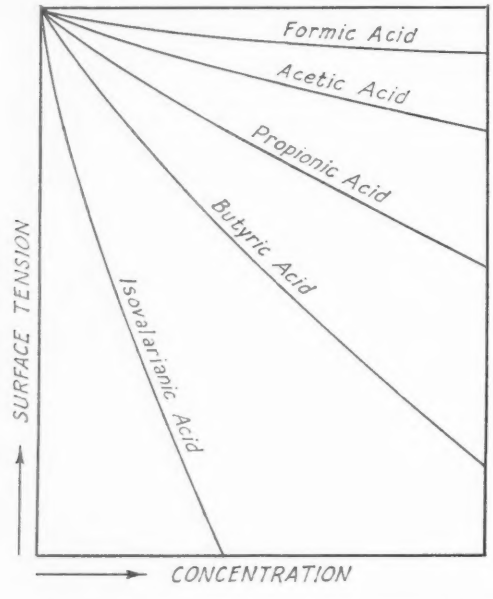

FIG. 4.—Graphic representation of decrease of surface tension by organic acids, according to Traube's rule.

even a very small amount of oil (0.5 cc.) and consequently its capacity was marked "zero." Yet when large amounts of oil were mixed with the humus and the settled residue later examined under the microscope, some oil was found trapped in the sediment. All of the other sediments will hold more oil than is indicated in the graphs (Pl. I), for with an

TABLE II

AMOUNT OF OIL IN CUBIC CENTIMETERS CARRIED DOWN BY 1 GRAM OF VARIOUS SEDIMENTS

Sediment	*Size**	*Deflocculation Time*		
		5 Minutes cc.	*10 Minutes* cc.	*30 Minutes* cc.
Decorah shale	A	0.20	0.60	1.25
	B	0.20	0.46	1.50
Blue Earth silt	A	0.40	1.75	2.75
	B	0.40	1.25	1.50
Marl	A	1.70	1.15	1.50
	B	0.75	1.15	1.50
Bentonite	A	0.15	0.30	0.75
	B	0.20	0.75	2.00
Diatomaceous earth	A	0.50	1.00	1.50
	B	0.50	1.00	1.50
Oil shale	A	0.10	0.25	0.40
	B	0.50	0.75	1.00
Humus	A	0.00	0.00	0.00
	B	0.00	0.00	0.00
Calcareous silt	A	0.50	0.75	1.00
	B	0.75	0.85	1.25
Calcareous shale	A	0.30	0.40	0.80
	B	0.40	0.80	1.50
Sand and silt	A	0.30	0.70	1.25
	B	0.30	0.70	1.25

* Size A = ½–¼ mm.; B = less than ¼ mm.

excess floating, the sediment at the bottom of the tube is darker due to more trapped oil. Thus, the amounts plotted in Plate I are the maximum amounts that can be completely carried down.

OBSERVATIONS

Microscopic examinations of the oil-sediment mixtures that settled in the sedimentation tubes showed that the oil is carried down in two somewhat different ways. In most sediments it occurs as microscopic globules. In sediments laden with organic particles, however, it occurs

as irregular, flaky, and stringy forms (Figs. 2 and 3). This difference is believed to be due to variance in surface tension or interfacial tension. The spheres are characteristic of an ordinary oil-water emulsion where there is sufficient surface tension to cause the drops to assume the least possible surface area. The flaky forms show a tendency for the oil to spread out rather than to retract.

An explanation of this difference in surface tension may be found in a fundamental colloidal principle known as Traube's rule.[5] This rule states that organic acids lower surface tension and that the higher members of a homologous series of organic compounds have the greatest effect in lowering the surface tension of their watery solutions (Fig. 4.)

In the sediments used for these experiments, organic residues are most abundant in the humus soil and in the oil shale. The lowering of the interfacial tension may be responsible for the very small amount of oil carried down by both of these sediments.

METHOD OF OIL SETTLING

Murray Stuart[6] did some experimental work with oil-clay mixtures and decided that the oil is broken up into separate particles by the deflocculation and assumes spherical shapes due to the interfacial tension between oil and immiscible water. This mixture would correspond to an oil-water emulsion except for the effect of the sediment particles (he used Kama clay from Burma). These particles are non-metallic, and, similar to all ordinary gangue materials, are first wet with water, therefore not with oil. The oil globules in an ordinary emulsion could come into contact with one another and coalesce, finally forming two simple layers of water and oil, but in the muddy solution the oil globules are held apart by the particles of mud. These particles of mud are wet with water and therefore are not miscible with the oil globules. Neither can the oil globules come together owing to the fine state of division in which the mud particles exist. The oil globules, therefore, are carried down mechanically, mixed with the mud particles.

This theory of mechanical carrying down of the oil globules by the water-wet sediment does not agree with the observations of any of the sediments in this series of experiments. Microscopic examinations of deposited water-oil sediment mixture show the oil particles in a loose state of packing with the mineral grains actually adhering to the oil. Observation demonstrates that the oil globules are held down by the weight of the adhering grains and not by mere mechanical trapping.

[5] H. N. Holmes, *Laboratory Manual of Colloidal Chemistry*, p. 64. London (1928).

[6] M. Stuart, *The Geology of Oil, Oilshale and Coal*. London (1926).

It is true that the basis of oil flotation is the preferential wetting of metallic surfaces, resulting in bubble attachment and rising, and that the gangue material shows little oil-wetting effect, so remains at the bottom. That does not mean, however, that the gangue is not oil-wet to some extent. This fact of gangue oil wetting has been demonstrated by A. W. Farenwald[7] in experiments determining the thickness of oil film collected on mineral surfaces. The minerals listed on the basis of amount of oil adsorbed range from galena at the top of the list down to quartz at the bottom. The important fact to note is that quartz did adsorb a measurable amount of oil.

Farenwald also makes the statement that "chemicals profoundly affect the oil-collecting properties of minerals. The normal order of minerals in their oil-collecting capacity may be entirely upset by the presence of a small amount of electrolyte in solution."

The 3 per cent sodium chloride in sea-water solution used in these experiments might produce some such effect on the gangue minerals.

Another factor to be considered in the flocculating and carrying down of the oil and mineral grains is the presence or absence of electrical charges. This is thought to be important[8] for if the oil and the mineral particle have like charges of sufficient magnitude they will repel and there will be no "oiling" of the grain. Flocculation means low or slight electrical charge on mineral particles and an additional effect of the NaCl electrolyte would be to neutralize any charges on the oil and mineral particles. Coagulation and settling would then take place.

Quartz, calcite, and other gangues are capable of adhering to oil globules and any repelling electrical charges present should be neutralized by the NaCl electrolyte. These facts account for the oil globules settling under the weight of clinging mineral grains.

The curves in Plate I show a marked difference in the oil-settling capacities of the sediments tested. The chief variables in the experiments were (1) grain size, (2) character of the oil emulsions, and (3) mineral content.

The grain-size factor is important because the forces attaching the oil and the sediment are probably weak and directly proportional to the surface area per unit weight. Small grains would be efficient depositing agents because they have large surface areas per unit weight; the larger particles, on the other hand, would not adhere to the oil globules because of too much weight per unit of attracting force.

[7] A. W. Farenwald, "Surface Reactions in Flotation," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 70 (1923).

[8] O. C. Ralston, "Why Do Minerals Float?" *Min. and Sci. Press* (October 23, 1915).

Humus soil and oil shale illustrate the importance of the character of the emulsion. The oil shale is considerably below Decorah shale in the list of sediments ranked according to oil settling (Table III). The

TABLE III

SEDIMENTS LISTED IN ORDER OF THEIR OIL-SETTLING CAPACITIES. EMULSION WITH ONE GRAM OF SEDIMENT USED IN EACH

Sediment	*Maximum Amount of Oil (Cubic Centimeters)*	*Average Amount of Oil (Cubic Centimeters)*	*Predominating Mineral*
Kaolin	2.50	1.21	Clay minerals
Blue Earth silt	2.10	1.33	Quartz
Marl	1.50	1.11	$CaCO_3$
Diatom. earth	1.50	1.00	Silica
Decorah shale	1.37	0.70	Sericite, clay minerals
Bentonite	1.35	0.68	Montmorillonite
Sand-silt	1.25	0.75	Quartz, sericite
Calc. shale	1.15	0.70	$CaCO_3$, sericite
Calc. silt	1.12	0.85	$CaCO_3$, quartz
Oil shale	0.70	0.60	Sericite, organic material
Humus	0.00	0.00	Organic material

oil shale is a more firmly cemented rock and not as easily broken down to fine particles, and also the presence of organic acids accompanied by the lowering of the interfacial tension could account for this low settling capacity. As already suggested, a low interfacial tension might allow the buoyant effect of a globule of oil to exceed its internal coherence, allowing part of the oil to break away and rise.

The mineral content of these fine-grained sediments showed no direct relationship to the amount of oil carried down.

TABLE IV

PIPETTE ANALYSIS OF DECORAH SHALE SHOWING GRAIN-SIZE FRACTIONS OF 1/32 MILLIMETER DIAMETER AND FINER

Size (Mm.)	*Weight of Fractions after Stirring*		
	5 Minutes	*15 Minutes*	*30 Minutes*
1/32	0.114 gr.	0.154 gr.	0.176 gr.
1/64	0.072 gr.	0.119 gr.	0.143 gr.
1/128	0.012 gr.	0.010 gr.	0.010 gr.
1/256	0.007 gr.	0.008 gr.	0.009 gr.

A third factor to consider in the discussion of experimental results is the reason for the increased oil capacity with increased time of dispersion. This is influenced by the fineness of the emulsion and a finer disintegration of the sediment. To ascertain the relative importance of these changes, the Decorah shale and the Blue Earth silt were ana-

lyzed by the Krumbein pipette method to determine the grade size distribution after 5 minutes, 15 minutes, and 30 minutes in the dispersion machine.

The Decorah shale analysis shows that the coarse material greater than 1/32 millimeter size broke up into finer grains which lie in the range of this analysis. Observation of the residue on the bottom of the graduated cylinders containing the differently stirred mixtures showed a progressive volume increase due to greater fineness.

TABLE V

PIPETTE ANALYSIS OF BLUE EARTH SILT SHOWING GRAIN-SIZE FRACTIONS OF 1/32 MILLIMETER DIAMETER AND FINER

Size (Mm.)	*Weight of Fractions after Stirring*		
	5 Minutes	*15 Minutes*	*30 Minutes*
1/32	0.162 gr.	0.116 gr.	0.169 gr.
1/64	0.139 gr.	0.098 gr.	0.146 gr.
1/128	0.121 gr.	0.083 gr.	0.121 gr.
1/256	0.098 gr.	0.070 gr.	0.104 gr.
1/512	0.075 gr.	0.065 gr.	0.076 gr.
1/1,024	0.067 gr.	0.046 gr.	0.063 gr.

The Blue Earth silt results are not a progression toward finer material. The 15-minute figures do not conform with the 5-minute and 30-minute columns, but the indication is that the sediment did not break up during dispersion.

Thus, the continued breaking up of the oil globules appears to be the only change causing increased oil-settling capacity of the silt. This would allow the smaller oil particles to be carried down with less attached sediment, and a more intimate mixing of the oil and fine silt, resulting in greater settling efficiency.

The Decorah shale is influenced by both the breakdown of the grains and by the emulsion becoming finer. The other sediments may be controlled by the emulsion alone or by a combination of both.

Consequently, the increased oil-settling capacity of a sediment is due to continued breakdown of the particles and increased fineness of the oil-water emulsion.

SUMMARY

Laboratory observations warrant the following conclusions.

1. Sediments vary considerably in their oil-settling capacities.

2. Fine-grained sediments are able to carry down more oil than coarser-grained particles. Bentonite clays may be an exception.

3. Aside from bentonite, there is no obvious correlation between the mineral composition of a fine sediment and its oil-settling capacity.

4. The oil in the form of microscopic globules is carried down and held by the weight of adhering mineral particles.

5. Organic acids decrease a sediment's oil-settling capacity. This may be due to the lowering of the oil-water interfacial tension.

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TRACE-SLIP FAULTS[1]

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ABSTRACT

A trace-slip fault is one on which direction of movement is parallel with the trace of planar elements on the fault plane. It is characterized by lack of the usual stratigraphic criteria of faulting. Several cases of trace-slip faults encountered in the field are presented. It is shown that many of the features of transverse epi-anticlinal faults in oil fields of the Rocky Mountain region, such as rapid variation in throw, offset of axial plane, and apparent pivotal character, can be accounted for by translatory oblique movement. A method for graphic study of oblique movement on faults cutting curved or intersecting planar elements is described.

INTRODUCTION

Field observations on faults are seldom complete. A geologic map of faulted stratified rocks commonly shows surface traces of faults as inferred from offset, omission, and repetition of beds in a known stratigraphic succession. Dip of fault is, in many places, obtained from its trace across irregular topography or from a small exposure of a fault wall. It is unusual to obtain adequate data on direction of movement. Even grooves on a fault wall may be misleading; they show the direction of the last movement, which may be different from one that produced major displacement. It is commonly assumed that movement on a fault is normal to its strike or, on a tear fault, parallel to its strike. These assumptions are ordinarily adequate. In some places, however, recognition of approximate direction of oblique movement is essential to an understanding of relations of faults and folds.

In the Medicine Bow Range of southeastern Wyoming there are faults for which direction of oblique movement can be deduced fairly accurately. It is the purpose of this paper to present observations on some of them, to point out relations possibly caused by oblique movement on epi-anticlinal faults found in many oil-bearing anticlines in the Rocky Mountain region, and to develop the concept of a trace-slip fault as a useful one in elimination among a number of different movements that could have produced observed relations.

The writer wishes to thank A. F. Hagner of the department of geology, University of Wyoming, for reading the manuscript.

TERMINOLOGY

Faults.—The descriptive fault terminology here used is, with one exception, that recommended by Reid and associates.[3] They give the following definitions for movements measured on the fault surface.

[1] Manuscript received, May 27, 1941.

[2] Department of Geology, University of Wyoming.

[3] H. F. Reid, W. M. Davis, A. C. Lawson, and F. L. Ransome, "Report of the Committee on the Nomenclature of Faults," *Bull. Geol. Soc. America*, Vol. 24 (1913), pp. 163–86.

Slip or net slip is the distance, measured on the fault surface, between two formerly adjacent points situated, respectively, on opposite walls of the fault.

Strike-slip is the component of the slip parallel with the fault strike.

Dip-slip is the component of the slip parallel with the fault dip.

Trace-slip is the component of the slip parallel with the trace of a bed, vein, or other surface on the fault plane.

Perpendicular slip is the component of the slip at right angles to the trace of a bed, vein, or other surface on the fault plane.

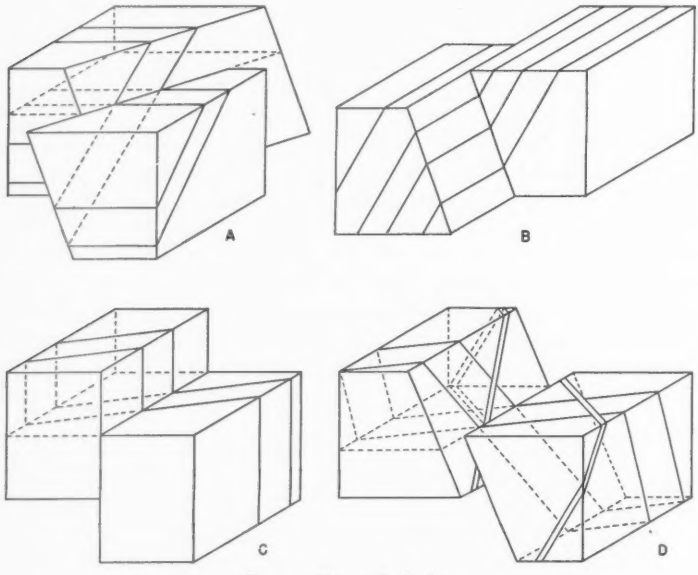

FIG. 1.—Trace-slip faults.

They use two of the terms as adjectives in *strike-slip fault* and *dip-slip fault*, designating respectively a fault on which net slip is parallel with fault strike, and one on which net slip is parallel with fault dip. The writer proposes *trace-slip fault* to designate one on which net slip is parallel with the trace of a bed, vein, or other surface on the fault plane, and *perpendicular-slip fault* for one on which net slip is perpendicular to the trace. If the fault cuts both stratification and a transgressive tabular body or surface, such as a dike, vein, or other fault, it is necessary to add a modifying phrase because a fault may have a trace-slip relation to stratification and some other relation to a vein cutting the beds.

Various trace-slip faults are shown in the block diagrams (Fig. 1). The most general case is an oblique-slip oblique fault (A). Specialized

cases are strike-slip strike fault (B), vertical dip-slip oblique fault cutting vertical beds (C), and dip-slip dip fault cutting vertical beds. D shows a trace-slip fault with respect to stratification; it approaches the conditions of a perpendicular-slip fault with respect to the dike. The dotted lines show that, after erosion has reduced both blocks to the same elevation, a trace-slip fault leaves no evidence in the form of offset, omission, or repetition. In this respect it is similar to a bedding fault.

Pitch and plunge.—The *pitch* of a line lying in a fault plane, such as the trace of a dislocated bed or vein, is defined by Reid and associates[4] as the angle between the line and the horizontal measured in the

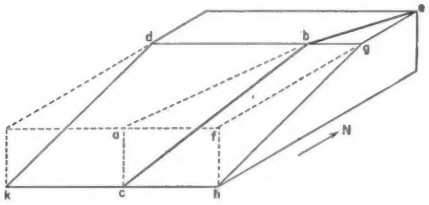

FIG. 2.—Pitch and plunge.

fault plane. Lindgren[5] defines pitch, as applied to ore-shoots, in the same sense, which is the one that seems to be generally acceptable to American mining engineers.[6] The term *plunge* was proposed by H. L. Smyth[7] to designate the vertical angle between a horizontal plane and the axis of an ore-shoot; this definition is accepted by Lindgren. Reid and associates[8] use *dip* for the angle measured in a vertical plane between a horizontal plane and the trace of a dislocated bed or vein on the fault plane, thus making dip and plunge synonymous. The writer believes that *dip* should be reserved for planar elements and *pitch* and *plunge* for linear.

The diagram (Fig. 2), constructed so that parallel lines in three-dimensional space are represented by parallel lines in the drawing, illustrates the terms here used. Line *bc* is the trace of a bed on fault plane *dghk*; *be* is a strike line on the bed; *dg* is a strike line on the fault. Pitch is angle *dbc*, in this case a few degrees less than a right angle. Plunge is angle *abc*, in this case a small one slightly less than angle *fgh*,

[4] *Op. cit.*, p. 181.

[5] W. Lindgren, "Mineral Deposits," 4th ed. (1933), p. 155.

[6] Discussion of R. W. Raymond, "Dip and Pitch," *Trans. Amer. Inst. Min. Eng.*, Vol. 39 (1908), pp. 898–916.

[7] *Op. cit.*, Raymond, p. 916.

[8] *Op. cit.*, p. 181.

dip of fault. In general, pitch and plunge are different in value. They are equal only if the fault is vertical, or if fault and bed happen to meet certain restricted conditions of strike, dip, and direction of dip. Another term used is *direction of plunge* to designate the course from a higher to a lower point on the trace of bedding on the fault, that is, course from *b* to *c* or *b* to *a*. In the diagram, direction of plunge is about S. 10° W.

EXAMPLES

Thrust and tear faults cutting folds.—The map (Fig. 3) represents, in generalized form, an area of a few square miles mapped by the

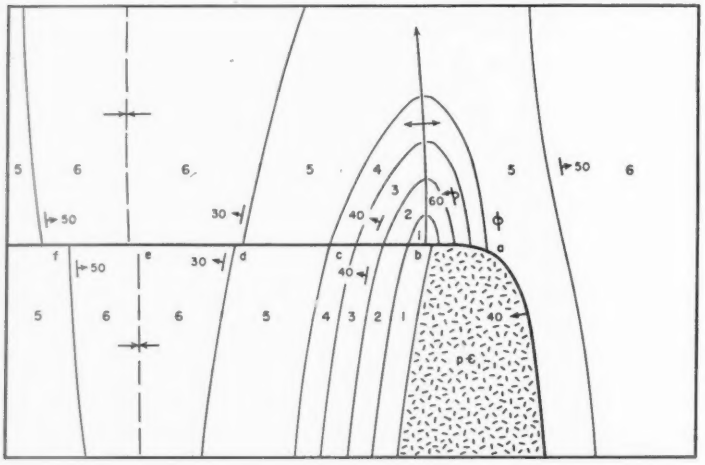

FIG. 3.—Map of faulted anticline and syncline.

writer[9] in T. 15 N., R. 77 W. The principal changes from the original map are extensive stripping of alluvium and restoration of probable relations beneath cover in the western part of the area.

Pre-Cambrian granites are overlain by Paleozoic and Mesozoic beds. There are no Tertiary dikes that might help in deduction of direction of fault movement. In the southeastern part a thrust fault dipping 40° west cuts the limb between overturned anticline and syncline. The thrust passes northwest into a nearly vertical tear fault striking west across the northward-plunging anticline. On the basis of stratigraphic criteria alone, the fault dies out in the short distance between *a* and *b*; another fault with downthrow on the north cuts the

[9] "Structure of the Southwest Margin of the Laramie Basin, Wyoming," *Bull. Geol. Soc. America*, Vol. 49 (1938), pp 1515–44.

syncline between *d* and *f*. The conclusion might be reached that the area was subjected to two unrelated periods of deformation, one under compression and the other under tension.

Considered in terms of angular relations of trace of stratification and movement on the fault, the following conclusions are reached. The thrust is a dip-slip fault, and the tear is an oblique-slip fault on which a line representing direction of movement plunges close to west at 40°. Between *a* and *b* line of movement and trace of stratification on the fault intersect at a large angle; there is, consequently, abundant stratigraphic evidence of faulting. Between *b* and *c* the tear is a trace-slip fault. At *d* plunge of line of movement is about 10° greater than plunge of trace of stratification, and there is a small offset indicating downthrow on the north. Offset at *e* is greater than at *d* because the

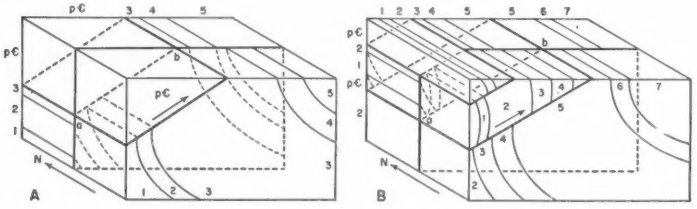

FIG. 4.—Intersecting thrust and tear faults.

trace of the axial plane of syncline on the fault is nearly vertical. Offset at *e* is approximately equal to strike-slip, and consequently net slip of tear decreases from *a* toward *e*. Offset at *f* is greater than at *e*, in spite of westward decrease in net slip, because at *f* the tear is a perpendicular-slip fault.

The line of reasoning above should be used with considerable circumspection in dealing with tear faults. Its validity is dependent upon the assumption that movement is translatory. Several other tears which the writer has mapped in detail provide evidence of more or less independent folding and thrust faulting in the blocks separated by the tear. In these cases inferred direction of linear movement can be applied only in the immediate vicinity of the place providing data for inference.

Intersecting tear and thrust faults.—The example presented in Figure 4A is a modification of two cases encountered by the writer,[10] one in Sec. 26, T. 14 N., R. 77 W., and the other in Secs. 5 and 8, T. 13 N., R. 76 W. The principal modifications are reduction of the surface to horizontal and change of fault strikes so that they intersect at right angles.

[10] *Op. cit.*, Pl. 1.

A westward-dipping thrust cuts the limb between anticline and syncline. An eastward-striking vertical tear cuts pre-Cambrian crystallines, as shown in the field by offset of tabular metadiabase bodies in granite gneisses, and also cuts and offsets Paleozoic and Mesozoic beds. The faults intersect at the surface without one offsetting the other. The thrust is a dip-slip fault on which movement is parallel to *ab*; movement on the tear is in the same direction. Each of the faults is a trace-slip fault with respect to the other, and consequently neither offsets the other. Direction of movement on both faults makes a large angle with trace of stratification; there is consequently stratigraphic evidence of faulting in the form of omission of beds along the thrust and offset along the tear.

The two faults can be of the same or different age. The essential condition for absence of offset of one fault by the other is that lines of movement on both be parallel. This condition is not likely to occur in most instances. Differential resistance of rocks affected is likely to cause a slight rotation of blocks with respect to each other and consequently a slight divergence from parallelism of respective lines of movement. In this case one fault would offset the other, but the offset would be small in comparison with offset or stratigraphic separation of beds. A possible, but highly improbable, case is that of a pair of faults having a trace-slip relation to each other, cutting beds that are parallel to one fault plane and making traces on the other parallel to direction of movement. Under these conditions there would be no offset of one fault by the other and no offset, omission, or repetition of beds.

Certain relations of thrust and tear faults that are likely to be confusing are shown in Figure 4B. The western part of the diagram is drawn from the writer's map of Sec. 28, T. 20 N., R. 82 W.,[11] and the rest from a map of Sec. 17, T. 11 N., R. 76 W., Colorado. Although the two localities are 60 miles apart, the relations shown could occur together.

Two westward-dipping thrusts and a westward-striking vertical tear cut the limb between an anticline and a syncline affecting pre-Cambrian crystalline rocks and Paleozoic and Mesozoic sediments. Beds strike north; they are vertical, or have high normal dips to the east, or high reverse dips to the west. The rocks above the upper thrust are not cut by the tear. The lower thrust and the tear intersect without offset at *b*. West of *b* the beds are offset to the left; here, if one walks along the outcrop of a bed toward the fault, it is necessary to turn to the left to find the same bed on the other side of the fault. East of *b*

[11] "Structure of the Elk Mountain District, Carbon County, Wyoming," *Bull. Geol. Soc. America*, Vol. 52 (1941), pp. 1445–86.

the tear offsets beds to the right. If tear faults are not recognized as possible oblique-slip faults, but instead are assumed to be strike-slip faults, it would be difficult to explain the opposite directions of offset.

In order to avoid controversy as to whether the thrusts are overthrust or underthrust faults, it will be assumed in the following explanation that the rocks east of the place where the tear dies out eastward remained stationary and that all rocks in the diagram moved eastward during folding and faulting.

Movement on all faults was parallel with line *ab*. The tear is a trace-slip fault with respect to both thrusts; consequently, one fault does not offset another. Absence of offset of bed 1 at the land surface is reliable field evidence that the tear does not cut the block above the upper thrust, as stratification in this block is nearly normal to line of movement. Either the upper thrust is older than the tear, or the tear was initiated somewhere in the eastern part of the diagram and had not yet been propagated westward far enough to affect the rocks now in the block above the upper thrust at the time the thrust was initiated. During the later stages of deformation there was both movement along faults and movement of rocks by bending. In the block between the two thrusts and south of the tear the beds are almost vertical; the angle between trace of stratification on the tear and line *ab*, shown by dotted lines near *a*, is about 45° to 60°. In the block between the two thrusts and north of the tear the beds dip about 60° east; the angle between trace of stratification on the tear and *ab* is nearly a right angle. Distance in the south block from *a* toward *b* to the stratigraphic top of bed 4 is consequently greater than the corresponding distance in the north block. This difference in distances along *ab* produced offset to the left at the surface west of *b* great enough to counteract the right offset east of *b*. Other possible explanations of the opposed directions of offset along the tear depend on the angle between traces of stratification in the respective blocks, such as the angle between crossing dotted lines near *a*.

EPI-ANTICLINAL FAULTS

Description and genesis.—Many oil-producing elongate domes of the Rocky Mountain region are cut transversely by faults that have a number of features in common with oblique-slip tear faults. Estabrook[12] recognized that transverse faults of the Elk Basin field cut across the axial plane of the anticline and that displacement varies

[12] E. L. Estabrook, "Faulting in Wyoming Oil Fields," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), p. 98.

greatly along fault strike. He states that displacement may not be vertical, but may follow some oblique angle. Irwin[13] says,

> A few of the characteristics of the epi-anticlinal faults may be noted as follows:
>
> 1. The vertical displacements vary from less than 5 feet to 700 feet.
>
> 2. Faults are known to extend to depths of 3,000 feet in Salt Creek, and 1,500 to 2,000 feet at Lost Soldier. How much deeper they extend is not known.
>
> 3. Relatively elevated or depressed blocks bounded by parallel or converging faults are common.
>
> 4. Transverse segments of folds are often shifted along the trend of the faults which bound the segments. The movement may therefore vary from horizontal to vertical, and through any combination of the two. The most noticeable result of a horizontal component (strike-slip) in the movement is offset of the anticlinal axis in the various segments. The Garland, Baxter Basin, and Little Lost Soldier anticlines are good examples.
>
> 5. The faults are occasionally pivotal, downthrow at one end passing into upthrow at the other.
>
> 6. In some cases the faults affect the position of the oil-water contact; in others they do not.

Link[14] produced in a pressure box elongate domes cut by transverse faults. A push block shaped like a blunt plowshare was forced into the lower part of a succession of artificial sediments, which were permitted to expand laterally normal to compression. Because of the shape of the push block, the compressive stresses had a vertical as well as a horizontal component. The transverse faults developed under tension approximately normal to compression. He advances the hypothesis that short anticlines and domes in the Rocky Mountain foothill belt were caused primarily by differential stress transmission through the deeper-lying ancient massives.[15]

The hypothesis of differential stress transmission through a heterogeneous pre-Cambrian basement complex is now generally accepted as explaining many of the structural features of the eastern part of the Rockies. Major anticlinal mountain ranges in which the pre-Cambrian cores are exposed have various trends. There are unsymmetric folds only a few miles apart whose axial planes dip in opposite directions. Faults and minor folds do not fit into a simple pattern explicable in terms of uniform transmission of compression from the west. In southeastern Wyoming, where the pattern of folds and faults is extremely complex, the stratigraphic succession consists principally of

[13] J. S. Irwin, "Faulting in the Rocky Mountain Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), p. 124.

[14] T. A. Link, "Origin and Significance of 'Epi-anticlinal' Faults as Revealed by Experiments," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), pp. 853–66.

[15] *Op. cit.*, p. 862.

shales and sandy shales; thick massive limestones capable of extensive stress transmission are conspicuously absent. It seems highly probable that folds and particularly faults initiated in the heterogeneous pre-Cambrian rocks have exercised major control in the development of structures observed in the Paleozoic and Mesozoic sediments.

Some of the anticlines, such as Rock Creek[16] and Clay Basin Dome,[17] are a short distance from a high-angle thrust fault bringing pre-Cambrian rocks onto Upper Cretaceous beds, and are in the block beneath the thrust. The anticlines are marginal folds apparently formed, at least in part, by transmission of compression a short distance from a rising and advancing pre-Cambrian block out into the adjacent sediments. General direction of movement of rocks during formation of the anticline should be nearly parallel with movement on the thrust.

Other anticlines and domes occur in synclinal basins far from major thrusts. Many of them, especially those which are of no interest as oil traps because erosion has exposed possible oil-producing beds, are cut longitudinally on the steep flanks by high-angle thrust faults. It is probable that an anticline of this type was formed by initiation of a thrust in the pre-Cambrian crystallines, surfaceward propagation of the fault, and bending of beds over the top of the rising block. One would expect the fault to die out toward the surface and increase in dip in the same direction because of deflection of the growing fracture toward stratification in nearly vertical beds. General direction of movement of rocks during formation of the anticline should be nearly parallel with movement on the thrust.

Movement.—Although it has long been recognized that movement on many epi-anticlinal faults had a component parallel with strike, they have commonly been treated in oil-field work as dip-slip faults. On structural contour maps throw is shown by the elevation difference between contours on opposite sides of a fault. Study of the maps alone may lead to the conclusion that the relations shown were produced solely by vertical movement. For purposes of locating and logging wells the vertical conception is adequate. Its usefulness for other purposes is doubtful; it may cause failure to recognize possible intercommunication of different producing zones across faults, particularly well down the flanks of folds where the contour map is likely to be inaccurate and incomplete.

[16] C. E. Dobbin, H. W. Hoots, C. H. Dane and E. T. Hancock, "Geology of the Rock Creek Oil Field and Adjacent Areas, Carbon and Albany Counties, Wyoming," *U. S. Geol. Survey Bull. 806-D* (1929).

[17] *Op. cit.*, Irwin, p. 109.

The hypothetical cases (Fig. 5) illustrate some of the simpler possible relations on oblique-slip epi-anticlinal faults. A, B, and C are drawn to show purely translatory movement with no variation in net slip. D shows a rotatory fault with constant net slip.

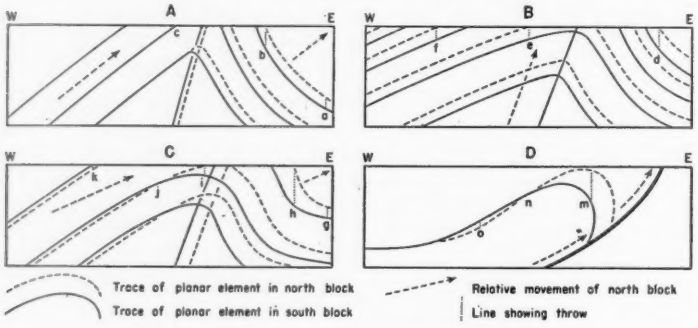

FIG. 5.—Sections in planes of vertical epi-anticlinal faults.

The fault in Figure 5A is a trace-slip fault with respect to stratification in the west flank of the anticline, and here there is consequently no stratigraphic evidence of faulting. Throw increases from *a* to *b*, remains nearly constant up to the axial plane, and decreases to zero at *c*. The axial plane is offset considerably less than the beds of the east flank. The rapid variation in throw is not caused by variation in net slip, but instead by variation in the angle between direction of movement and trace of stratification on the fault. It is probable that the case here discussed is representative of conditions in anticlines where known epi-anticlinal faults are confined to the steep flank. Lost Soldier dome may be an example.

Figure 5B represents a trace-slip fault with respect to the axial plane, which is not offset although the throw at *d* is considerably greater than at *e* and *f*.

In Figure 5C, pitch of line of movement is slightly less than pitch of trace of stratification in the west flank of the anticline. Throw is zero at *j*. To the west the north block is downthrown and to the east it is upthrown. Throw increases from *j* to *h* and then decreases to *g*. The fault has a number of the characteristics mentioned by Estabrook and Irwin; there is great variation in displacement, the axial plane is offset, and the fault is apparently pivotal about point *j*.

The thrust in Figure 5D has a dip of about 30° in depth and increases in dip surfaceward. An epi-anticlinal fault terminates downward on the thrust. The block north of the vertical fault advanced

farther east. In depth, where dip of thrust is constant, movement was translatory. The upper part of the north block, in addition to the translatory movement, underwent, with respect to the south block, a counterclockwise rotation as viewed looking horizontally north at the plane of section. In preparing the diagram the solid lines were drawn on paper and traced on a transparent sheet. The sheet was moved up to the east and rotated counterclockwise so that the thrust lines on the two sheets coincided. The dashed line was then pricked through the tracing from the solid line. Results are similar to those in C. Downward movement of the dotted line at *o* was, however, caused by the rotatory movement. This hypothetical example is drawn from mapped relations of a faulted elongate dome eroded down to the pre-Cambrian core.[18]

Deduction of direction of movement on a fault is facilitated by sectioning in the fault plane. It is suggested that, in working with this type of drawing, lines on one side of the fault be traced on transparent paper. Several trial movements of the tracing toward coincidence with lines on the other side will often eliminate all but one movement.

TRACE-SLIP FAULT AS LIMITING CASE

The following discussion excludes from consideration overturned beds, bedding faults, and unusual relations, such as thrusting of younger rocks onto older.

The upthrown block along a strike fault is the one in which older rocks are in contact with the fault, as stratigraphic evidence of faulting is produced by dip-slip only (Fig. 1B). In dealing with oblique and dip faults, the term upthrown block is commonly applied to the one in which older rocks are in contact with the fault or in which outcrops have been shifted in the direction of dip of beds. The upthrown block so identified may actually have moved down with respect to the so-called downthrown block. Figure 6 shows a bed *abcd* cut by an oblique fault *efgh*. If the south block moves up along a line between *dh* and *da*, older rocks in the north block are in contact with the fault, the north block is the one in which outcrops have been shifted in the direction of dip of beds, and the north block is apparently upthrown; it is actually downthrown with respect to the south block. If the south block moves up along a line between *dg* and *da*, it is apparently and actually relatively upthrown. The limiting case between these two is that of a trace-slip fault with movement along *da*. When considering relative elevation and depression of blocks along a dip or oblique fault, the critical question is one of direction of movement with respect to trace of stratification on the fault.

[18] *Op. cit.*, "Structure of Southwest Margin of Laramie Basin," p. 1530.

The position of the trace of a bed on a vertical dip fault is easily visualized; direction of plunge is direction of dip of beds; pitch and plunge are both equal to dip of beds. Under other conditions the angles necessary to describe position of the trace can be obtained graphically as follows.

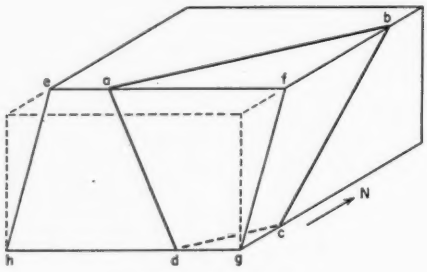

FIG. 6.—Oblique fault.

Strike and dip of beds and fault are plotted (Fig. 7A). A line normal to strike of fault is drawn through a point, such as *p*, that is above both fault and bed; this procedure is followed so that subsequent drawing will be on the surface or underground. Section B, normal to strike of bed, is drawn in order to obtain *bb'*, depth to the bed beneath *b*. Section C is constructed using dip of fault and *bb'* transferred from

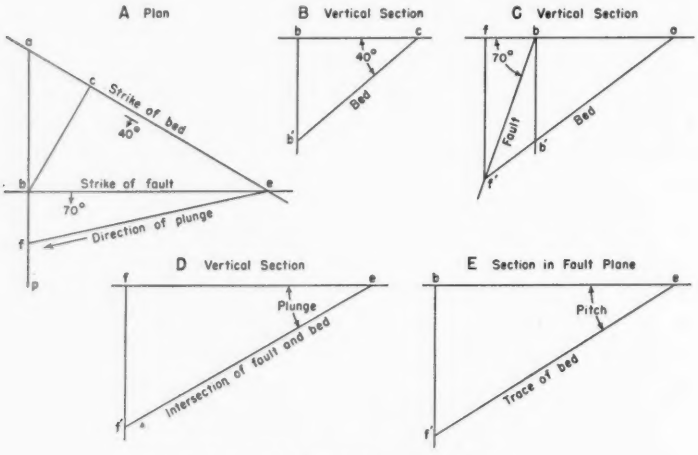

FIG. 7.—Solution for plunge and pitch.

Section B. Line *ab'* is drawn and prolonged to locate *f'*, a point below ground on both bed and fault. Point *f'* is projected vertically to the surface at *f*. Point *f* is transferred to A. Section D is drawn by transferring *ef* from A and *ff'* from C. Angle *fef'* is plunge. Section E is drawn by transferring *be* from A and *bf'* from C. Angle *bef'* is pitch.

General trigonometric formulas for pitch, plunge, and the angle between direction of plunge and strike of fault can be derived in terms of dip of bed, dip of fault, and the angle between strike of fault and strike of bed. One method of derivation involves the assignment of a value of unity to some line, such as *bc*, on the plan, the solution of a number of right triangles, and substitution and elimination among a number of equations. The graphic method is likely to be more easily applied by geologists and has the advantage that direction of plunge is clearly shown even when close to direction of dip of fault.

CONCLUSIONS

1. Trace-slip faults are characterized by lack of stratigraphic evidence of faulting.

2. Offset, repetition, and omission of planar elements by faulting are produced by movement across their traces on the fault.

3. Movement on pivotal faults along which a block is apparently upthrown at one end and apparently downthrown at the other is not necessarily rotatory about an axis normal to the fault plane at the point of no apparent displacement. The same result can be produced by translatory movement along a line whose plunge is the same as that of trace of stratification at the apparent pivot point and respectively greater and less than plunge of trace in opposite directions along fault strike away from the point.

4. Rapid variation in throw along a fault does not necessarily imply variation in net slip. The same results can be produced by constant net slip and oblique translatory movement across curved traces of planar elements.

5. A convenient type of drawing to study possible oblique movements on faults cutting curved planar elements, such as those in a transversely faulted fold, or cutting intersecting planar elements, such as beds and transgressive dikes and veins, is a drawing in the fault plane. If direction of movement can not be deduced readily by inspection, it is advisable to copy on a transparent sheet traces of planar elements in one block. Trial movement of the transparent sheet superimposed on the original drawing may lead to deduction of direction of movement.

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GEOLOGICAL NOTES

APACHE POOL, CADDO COUNTY, OKLAHOMA[1]

H. H. ARNOLD, JR.[2]
Tulsa, Oklahoma

A new Simpson sand producing area was discovered May 30, 1941, by The Texas Company in T. 5 N., R. 12 W., Caddo County, Oklahoma. The discovery well (Z. N. Smith No. 2, in the center of the SE. $\frac{1}{4}$, NW. $\frac{1}{4}$ of Sec. 2, T. 5 N., R. 12 W.) was located on the basis of seismograph exploration in the area. This test was completed in the Bromide sand at the total depth of 3,433 feet. The well produced at the rate of 60 barrels per hour, through 5-inch casing. The gravity of the oil is 39° Bé., corrected.

The name, Apache, has been given to the new pool. Since the discovery well, four additional producers have been completed, the largest of which averaged 300 barrels of oil per hour. Eleven tests are now drilling in the area.

The geologic section in the discovery well includes, from the surface to the total depth: Permian (0–1,450 feet), Hunton limestone (1,450–2,105 feet), Sylvan (2,105–2,345 feet), Viola limestone (2,345–3,205 feet), and Simpson formation (3,205–3,433 feet). The Bromide sand is penetrated at an average depth of 3,360 feet on structure. Wells somewhat lower structurally than the Smith No. 2 encounter short Woodford sections.

The only producing area adjacent to the Apache pool is the Cement pool, in T. 5–6 N., R. 9–10 W., approximately 14 miles east of Apache. The Cement pool, discovered in 1917, is producing from beds of Permian and Pennsylvanian age.

[1] Manuscript received, November 7, 1941.

[2] Division geologist, The Texas Company.

CORRECTION

POSSIBLE FUTURE OIL PROVINCES OF EASTERN CANADA

The following corrections should be made in the article, "Possible Future Oil Provinces of Eastern Canada," in the *Bulletin*, Vol. 25, No. 8 (August, 1941), and in the book, *Possible Future Oil Provinces of the United States and Canada*.

Bulletin	*Book*	
P. 1540	108	Fig. 3. Williams Sound should be *Williams Island*.
P. 1551	119	paragraph 2, line 7. Delete question mark.
P. 1552	120	Fig. 12, last column. After Windsor series, non-marine should be marine and continental.

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DISCUSSION

STRATIGRAPHIC NOMENCLATURE[1]

H. G. SCHENCK *ET AL.*,[2] HOLLIS D. HEDBERG,[3] C. W. TOMLINSON,[4] J. E. EATON,[5] AND R. T. WHITE[6]

The following letter, not originally designed for publication, is a result of a request for criticism of the report of the Permian subcommittee (C. W. Tomlinson, chairman) of the Association committee on geologic names and correlations. Referred to, and discussed in part, by C. W. Tomlinson, in "Technique of Stratigraphic Nomenclature" (November, 1940, *Bulletin*, Vol. 24, No. 11, pp. 2038–46), it is here printed in full for the information of *Bulletin* readers interested in this subject.

DEPARTMENT OF GEOLOGY STANFORD UNIVERSITY, CALIFORNIA
March 7, 1940

Dr. C. W. Tomlinson
509 Simpson Building
Ardmore, Oklahoma

Dear Dr. Tomlinson:

The seminar in stratigraphy has given further attention to your subcommittee's report and to your several letters addressed to H. G. Schenck. The undersigned are sympathetic with your efforts, and we believe that you understand that our interest in your problem has arisen because of its bearing on procedure in stratigraphy—the subject of our deliberations over a period of two years. We grant that we are given considerable freedom in our comments because of the fact that we do not have to make concrete suggestions, yet perhaps our ideas may be of some value to your subcommittee.

We also wish to make clear our stand: we are chiefly concerned with the scientific procedure in this problem. We must accept the facts as you present them. For example, we are not deeply concerned whether you put the Ochoa series in the Permian or not. We are concerned, however, with your reasoning. Our scientific training has taught us—and our more experienced colleagues still teach us—to draw no conclusions which are not supported by facts. Therefore, when you confess in your letter dated December 26, 1939, that you have no adequate evidence to prove that the Ochoa series is Permian, that it might be Triassic, we are convinced that you have extended your conclusions beyond your facts. Without adequate evidence, the Ochoa series can be included in the Permian system only questionably.

[1] Manuscript received, December 2, 1940.

[2] Stanford University, California.

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[5] 2062 North Sycamore Avenue, Los Angeles, California.

[6] Barnsdall Oil Company, Bakersfield, California.

We believe that you are entitled to set up any system of classification you want, to adopt any system of nomenclature you desire by such standards as you set up for yourself, and to reject at will the facts which you consider irrelevant. However, we would have been more impressed if you had offered your professional peers a more thoroughgoing discussion of the principles as discussed by other committees similar to yours. Thus, you adopt such terms as "Wolfcamp series" and "Leonard series." You do not give reasons for your failure to refer to the recommendation made by the International Geological Congress (1881 and others) that the names of series should end in the suffix "ic." If you were to accept the recommendations of earlier committees, you would speak of the "Wolfcampic series," the "Leonardic series," and so on. Furthermore, you go to considerable length to justify calling the Permian a system. The Permian has been widely used as a system by others for nearly a century.

As a final remark to this preface, please realize that we are analyzing your subcommittee's endeavors, as scientists analyze the scientific work of other scientists. Surely you will agree that weight of authority should not enter into such analyses. That your subcommittee counts among its members men of high standing in the Geological Society of America and the American Association of Petroleum Geologists is laudable, but it scarcely makes their every word inviolable. We are concerned with Science, not with personalities.

After a careful study of the "Auxiliary Standard Permian of America" as proposed by your subcommittee and in reply to your invitation for comments, we submit for your consideration the following alternative scheme which, in our opinion, might serve as a provisional "Standard Permian of the World." We also believe that such a biostratigraphic standard could be used for the Permian section of Texas.

Before proceeding with the actual scheme, we wish to question the advisability of the use of the term "series" as it has been applied by your subcommittee to such units as Wolfcamp, Leonard, Guadalupe, and Ochoa. We realize that it is not the intention of your committee to stabilize and to define the Lower, Middle, and Upper Permian. However, one can not overlook the fact that these terms (Lower, Middle, and Upper Permian) have been, are, and in the future will be, used by paleontologists and stratigraphers abroad as well as in America. According to standards best known to us and in conformity with wide usage, THESE are the units which are to be ranked as SERIES. As you no doubt know, in Russia the prevailing usage is to divide the Permian system into Lower Permian (Sakmarian+Artinskian+Kungurian stages) and Upper Permian (Kazanian+Tartarian stages). In America, the Permian system is divided into Lower, Middle, and Upper and there appears to be no unanimity of opinion as to what should be included in the Middle Permian. In view of the above, we appeal to you to reconsider your stand and instead to agree upon some arbitrarily set limits for each of these SERIES.

A recommendation from an organized group of leading stratigraphers and paleontologists such as your subcommittee represents will materially contribute toward a uniform and more precise usage of the terms Lower, Middle, and Upper Permian. We feel confident that such a move by your subcommittee will be welcomed by those who, like ourselves, are not in a position to give this problem the time and effort that it requires, but who, nevertheless, are likely to find themselves confronted, in teaching or research, with some aspects of this problem.

Moreover, we take exception to Dunbar's unwarranted use of the word "series" with such terms as *Sakmarian* and *Kungurian*. By original definition and by general usage these are *stages*. The technical word "stage" in stratigraphy is not synonymous with the term "series."

We offer for your consideration the following scheme of classification of the "Standard Permian of the World."

System	*Series*	*Stages*
Permian	Upper Permian	Djulfian Penjabian (Punjabian)
	Middle Permian	Guadalupian
	Lower Permian	Artinskian Sakmarian

Basing our recommendation in part on the excellent, detailed stratigraphic and paleontologic studies in the Southern Urals by Ružencev (1936, 1937) we agree that the Sakmarian stage should be taken as the lowermost division (stage) of the Permian system. The scope of the Sakmarian stage as established by Ružencev is practically the same as that of the "Wolfcamp series" proposed by your subcommittee. The Sakmarian stage, however, is preferred to the "Wolfcamp series" for the following reasons.

1. The lower boundary of the Sakmarian stage is drawn by Ružencev in a continuous fossiliferous section with no physical break or hiatus such as is present in the "Standard Permian of Texas" proposed by the subcommittee. It therefore follows that at least this part of the sequence is more completely represented in the Southern Urals than it is in Texas. The boundary drawn in an uninterrupted section has a greater likelihood of being stable than the boundary drawn at a disconformity, as is proposed by your subcommittee. Sooner or later, sediments corresponding in age to the time represented by the hiatus in Texas will be found on this continent; and again the problem will arise as to whether these intermediate beds should be placed in the Carboniferous or Permian. Furthermore, it appears to us that a part of the Southern Ural section does correspond in time to the hiatus in Texas. One therefore may ask: Where does this part of the section from the Urals fit in the "Standard Permian of America"? It seems that there is no place provided for it by your subcommittee's scheme. In conclusion, the deliberate placing of the Carboniferous-Permian boundary at a disconformity, the subcommittee's decision, is not a progressive move and is not likely to be a stable placement.

2. The definition of the lower limit or the base of the Permian system as given by your subcommittee appears to be ambiguous and perhaps even misleading. The subcommittee states that the beds marked by the "abrupt incursion of the fusulinid genera *Schwagerina* (*sensu stricto*), *Pseudoschwagerina* . . ." should be regarded as the base of the Permian. This statement implies that the genera *Schwagerina* and *Pseudoschwagerina* appear suddenly and at the same time. The truth of this statement may be questioned. The genus *Schwagerina* in Texas (Cheney, 1940) as well as in Russia appears earlier than *Pseudoschwagerina*. In Russia, the earliest specimens of *Schwagerina* are reported to occur in association with abundant *Triticites* in the beds which are referred to the Upper Carboniferous (Rauser-Černoussova, 1938). Dunbar and Skinner (1937) report *Schwagerina* in the Uralian of Russia. From the above it follows that the base of the Permian in the section where

only *Schwagerina* is present does not represent the same stratigraphic level as the base of the system established on the basis of *Pseudoschwagerina* alone.

Ružencev places the base of the Permian system (the base of the Sakmarian stage) at the first appearance of the genus *Pseudoschwagerina* and the associated forms. There is therefore only a very slight difference in the stratigraphic position of the Carboniferous-Permian boundary as drawn by Ružencev and that delineated by your subcommittee. A slight change of the boundary on the part of the subcommittee would reconcile the two classifications and thus contribute to uniformity and to precision in the definition of the scope of the Permian system.

3. The advantage of accepting Ružencev's definition of the base of the Permian system also lies in the fact that it will necessitate little, if any, revision of the stratigraphic units now widely used in Texas. It will be unnecessary, for instance, to modify the scope of the Cisco group by removing from it the Harperville formation (Cheney, 1940), which contains the earliest specimens of *Schwagerina* and which was previously regarded as the upper part of the Cisco group of the Upper Carboniferous. In other words, Ružencev's boundary is more in agreement with the established usage in the state of Texas itself than is the boundary proposed by the subcommittee.

The fauna listed by Ružencev from the Sakmarian stage and the overlying Artinskian stage appears to be adequate for a correlation of the Russian units with the Wolfcamp and the Leonard. It thus appears that the lower two stages of the Permian system in Russia correlate with the two so-called SERIES proposed by your subcommittee. Such a correlation was also indicated by A. K. Miller (1938). Since the Wolfcamp beds correspond to the Sakmarian stage and the Leonard beds correspond to the Artinskian stage, as redefined by Ružencev, then what need is there to introduce two new time-stratigraphic terms in the nomenclature of the standard section of the Permian?

It should be mentioned in passing, however, that in the past the scope of the Artinskian stage has been differently understood by different workers. We accept the Artinskian stage as defined by Ružencev (1936, 1937).

We endorse whole-heartedly the introduction of a new stage above the Artinskian stage, but we object to the use of the term "Guadalupe." In conformity with the recommendation of the International Geological Congresses, the stage terms should have an ending "ian." Furthermore, the term *Guadalupian* already has been proposed by Girty (1902). We suggest, therefore, that the term "Guadalupe series" be replaced by the expression "Guadalupian stage." We are not in a position to enter into a discussion regarding the subcommittee's revision of Girty's Guadalupian, that is, the subcommittee's withdrawal of the basal unit from the Guadalupian of Girty. We feel confident that the subcommittee's careful evaluation of the facts convinced them that this basal unit correlates with the top of the Leonard formation (Artinskian stage). We are thus forced to agree that the subcommittee was correct in omitting Girty's basal unit from the restricted Guadalupian stage.

In passing, may we again call the subcommittee's attention to the desirability of recommending that the part of the Permian sequence represented by the restricted Guadalupian be regarded as the Middle Permian.

The "Ochoa series," consisting of evaporites and other continental deposits, can not be accepted as the uppermost part of the standard Permian.

How can such a unit serve as a standard stratigraphic measuring rod when nothing is known of its faunal content? The standard divisions of the Upper Permian in Russia, the Kazanian and Tartarian stages, are unsuitable for essentially the same reasons. We regret very much that we can not offer the subcommittee a satisfactory substitute for the "Ochoa series"—one that will have all the needed qualifications; but we are willing to suggest the following next-best scheme for the Upper Permian. This, of course, will have to be regarded as a tentative arrangement only.

In India there are marine fossiliferous beds (upper part of the "Productus limestone") which carry a fauna characterized by the ammonite genus *Cyclolobus*. The same fauna has been also recognized in Pamir, Madagascar, and Timor. Miller (1938) holds the view that this *Cyclolobus* fauna "is probably younger than the youngest Paleozoic ammonoid fauna known from America." The name Penjabian[6a] was applied by De Lapparent (1893) to this section in India. A critical revision of De Lapparent's Punjabian is necessary so as to eliminate the possible overlap with that part of the section which is now designated as the Guadalupian stage. Perhaps the subcommittee might find it profitable to investigate the possibility of employing the name Punjabian for the stage immediately succeeding the Guadalupian stage. The lower limit of the Punjabian stage may be defined in terms of the upper limit of the Guadalupian stage, but the upper boundary of the Punjabian, unfortunately, will have to remain more or less indefinite until such time as a more complete sequence is discovered and studied.

The very top of the "Productus limestone" in the Salt Range of India is overlain conformably by the Lower Triassic *Otoceras*-bearing beds and lacks a completely diagnostic faunal assemblage. But in Djulfa (Armenia), the uppermost Paleozoic strata which underlie the Lower Triassic beds carry a distinctive assemblage characterized by the cephalopod genus *Prototoceras*. We suggest that the name Djulfian be employed for the uppermost Permian stage. Only the upper stratigraphic limit of the Djulfian stage can be defined at present. This upper limit will be determined by the lowermost Triassic *Otoceras*-bearing beds. The lower limit, however, will have to be left undefined until the Punjabian and Djulfian stages are found in one continuous section in some part of the world.

The above will, admittedly, provide us with only a tentative scheme until the Upper Permian section is better known; but even in the face of several shortcomings, the proposal offered is thought by the present group to be more useful and serviceable than a classification utilizing the Ochoa evaporites can possibly be.

We also feel that any scheme for the Upper Permian proposed at this date is only a temporary arrangement. The time is not far distant when some of the little-studied areas (such as in India, Iran, Afghanistan, and Timor) will yield more complete information concerning the succession of the Upper Permian marine strata and faunas.

A topic which we feel received inadequate consideration in your reports is that of the practical value of understanding the time-stratigraphic concept, and its corollary, dual nomenclature. Several careful readings of your report and letters prove to our satisfaction that this concept is not easy to grasp. We have found by experience that once a geologist who has had considerable

[6a] The spelling Punjabian is preferable.

field and laboratory experience does finally see that there is a difference between time units, rock units, and time-rock units, he immediately becomes enthusiastic and wonders why more of his associates do not strive to comprehend these units too. We are among the enthusiastic individuals who believe that it is worth while to proselytize openly and frankly for this "pet idea." We trust that your subcommittee, in its habitual judicial spirit, will in its turn sympathize with our sincere efforts to show the utility of the concept. If we can convert you, we are positive that you too will discover that the separation in thought and by name of rock units from time-stratigraphic units is applicable to your local needs.

Few field geologists need to be told what constitutes a mappable unit in a given area. Any qualified geologist is capable of mapping a contact between a predominantly shale unit and a predominantly sandstone unit. Fossils aid him in mapping when the outcrops are not continuous and in correlating the surface with the subsurface section. They assist him in determining folds and faults and help him in compiling composite geological columns. But if in surface mapping he relies solely upon the occurrences of supposedly diagnostic species, his map might never be completed: in many cases he would have to revise it constantly by drawing higher and higher or lower and lower parallel lines as he collects more fossils from different levels. For example, the Sespe formation in the western Santa Ynez Mountains of Santa Barbara County, California, is a cartographic unit below the Vaqueros formation and above the Gaviota formation. The Sespe and Gaviota formations are clearly separable on a lithologic basis in the vicinity of Cañada de Santa Anita. No geologist would think of mapping a contact at any other place than at the base of the massive sandstones resting upon the upper Gaviota siltstones. Yet, if the highest occurrence of *Turritella variata*, a supposedly diagnostic fossil, were used as the sole criterion for mapping the formations, the contact on the geologic map would have to be some six hundred feet stratigraphically above the striking and self-evident lithologic change. The attempt to make cartographic lines coincide with time lines here, as in many other regions, would lead to absurd results.

Advantageous though fossils may be as time-pieces for the geologist, nevertheless it is this chronological value that often confuses both stratigraphic terminology and classification. This is primarily because presumed total ranges of accepted "index fossils" have so often caused artificial divisions of cartographic units. Witness, for example, Goudkoff's report on the Reef Ridge shale in his paper on Kettleman Hills. Faunal breaks in the middle of a monotonous sequence of beds have led to the introduction of many formational names. These formations, however, can not be mapped on the ground by even the most qualified, competent, and discriminating field geologist. The divisions of the rock column made by paleontologic criteria are generally not cartographic units but divisions of another kind. They are time-stratigraphic units.

Thus, in dealing with sedimentary rocks, the geologist is concerned with two separate—two distinct—sets of units. The first of these kinds of units is physical, lithogenetic in make-up. Such a unit is called a formation by American workers. It is a sequence of strata that the geologist can represent on his field map. The second type of unit, on the contrary, is composed of a sequence of strata delimited by the paleontological record. Vertical ranges

of species have significance here. Rocks of different facies in this second type are classified under the same name. Several formations in many localities may fall into the same time-stratigraphic unit, or one formation may embrace several time-stratigraphic units by paleontologic data.

Stratigraphers, therefore, need a dual nomenclature: one set of names for cartographic units and one for sediments deposited during a given interval of time. The first category fills the need of the field geologist. The second category is chiefly for the purpose of correlation and the simplification of regional nomenclature. Local place names are used to designate the mappable lithogenetic units. These local lithogenetic units may be pieced together into one unbroken geological column which in turn can be divided into units by paleontological criteria. These latter units are the time-stratigraphic units and are given names that are applicable to the entire geological province. Because they are different kinds of things, it is desirable that the two categories of units should have each a special sort of nomenclature.

We thus reaffirm our opinion that a dual nomenclature is as desirable in dealing with the Permian of North America as it is elsewhere. In your letter of December 9, 1939, you speak of "the great nomenclatural burden already carried by stratigraphers." This objection carried little weight with us. Few people have memorized all of the names in the Manhattan telephone directory, yet they can still use the telephone effectively. Wilmarth's lexicon can be consulted by any stratigrapher who has not specialized on the sequence of strata of a given district. Your report holds that you can see no objection to using the same name for the Leonard series and for the Leonard formation. A formation is a lithogenetic unit; it is a sequence of strata which the geologist can map. A series is a time-stratigraphic unit, not a lithogenetic one. Yet you are using exactly the same name for the two categories of units, of two different ranks. Your subcommittee fails to see any likelihood that confusion will arise from such usage, but when did your subcommittee become clairvoyant? If one can base opinions on what geologists have done in the past, we too can crystal-gaze and predict that confusion most certainly will arise. Adopt a dual nomenclature, we urge, so that the geologist can continue to map formations as he finds them in the field and so that the laboratory man can correlate them as he sees fit with the evidence he has at his disposal at the moment.

In conclusion, we hope that you will receive this letter in the same friendly spirit in which we send it. Our desire has been to coöperate; and our efforts have been enjoyable to us as well as instructive. Perhaps you may find in our report some information which will stimulate renewed thought on the subject of stratigraphic classification and nomenclature. If this is so, then we shall feel that we have made a contribution to your problem.

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Very truly yours,

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HOLLIS D. HEDBERG, Barcelona, Venezuela (December 30, 1940).—A discussion by C. W. Tomlinson in the November *Bulletin*[7] brings up again a number of controversial points with respect to stratigraphic nomenclature. Some years ago a discussion between F. A. Melton and J. E. Eaton was published in the *Bulletin*[8] in which Melton held that lithologic unity was the essential attribute of a formation whereas Eaton would extend his formations from their type localities strictly on the basis of time equivalence of strata. Following this discussion, the writer submitted a note emphasizing the value of both of these concepts in stratigraphic work and the importance of using two distinct sets of stratigraphic terms to express them: *rock-stratigraphic* terms to refer to purely lithologic or lithogenetic divisions of the stratigraphic column; and *time-stratigraphic* terms for reference to the deposits formed during the variously ranking divisions of geologic time. In this connection, the writer also recommended the wider usage in this country of *stage* as a time-stratigraphic term for deposits of regional extent of lesser rank than a series, unified by time equivalence, independent of lithologic variation, and approximately corresponding to the concept of Eaton's formation.

This note was returned by the editor of the *Bulletin* with the statement that it was believed unnecessary to publish it since the subject would be covered by a report in preparation by a special committee on stratigraphic nomenclature. However, the otherwise admirable report of this committee[9] failed to make any clear distinction between rock-stratigraphic and time-stratigraphic terms and even tacitly approved the use of *stage* as a time term for subdivisions of the Pleistocene! Discussion with several other stratigraphers showed that they held ideas similar to those of the writer with regard to the need for distinction between rock-stratigraphic and time-stratigraphic terms and the desirability of using the term *stage* as the fundamental regional unit in the time-stratigraphic category, and in 1934 H. G. Schenck, R. M. Kleinpell, and the writer presented a paper in abstract at the meeting of the Cordilleran section of the Geological Society of America as follows:[10]

[7] C. W. Tomlinson, "Technique of Stratigraphic Nomenclature," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 11 (November, 1940), pp. 2038–48.

[8] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 10 (October, 1932), pp. 1039–44.

[9] *Bull. Geol. Soc. America*, Vol. 44 (1933), pp. 423–59; *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 7 (July, 1933), pp. 843–68.

[10] H. G. Schenck, H. D. Hedberg, and R. M. Kleinpell, "Stage as a Stratigraphic Unit" (abstract), *Geol. Soc. Amer. Proc. 1935* (1936), pp. 347–48; *Amer. Geol.*, Vol. 64, No. 1 (1934), p. 70.

The committee report entitled "Classification and Nomenclature of Rock Units" offers the promise that questions involving the principles of nomenclature may receive consideration and we, therefore, present the following case for discussion. Stratigraphic terms fall into two fundamental categories: (1) rock-stratigraphic, and (2) time-stratigraphic units. The unit in the rock-stratigraphic category is the formation; it has lithologic and genetic significance but does not necessarily have time connotation. The unit in the time-stratigraphic category is the stage which although independent of lithology comprises the sediments deposited in any one region during a geologic age. This concept of a material stratigraphic unit, independent of lithology and bounded only by time lines, but of lower rank than a system or series, is believed to be of fundamental importance in inter-regional correlation. The stage has been employed as a stratigraphic term for more than a hundred years. While there has been some variation in definition it has generally retained a time-stratigraphic connotation. Its usage in this sense for the deposits of a geologic age was codified in 1901 by the International Geological Congress and it has been accepted as a standard stratigraphic term in most European countries. Recognition in this country is urged in the interests of uniformity in terminology and clarity in regional and inter-regional correlations. The authors deplore the use of stage as a time term or as a purely lithologic unit.

The paper itself was never completed beyond a rough draft copy which was not approved by all of the authors of the abstract and is still under discussion. It is therefore unfortunate that Tomlinson makes reference to the "manuscript" (apparently he has seen a copy of the draft) and not to the published abstract. The writer's own views, as outlined in another publication[11] diverge considerably in some respects from those expressed in this draft manuscript.

The point of fundamental importance which the authors of the abstract "Stage as a Stratigraphic Unit" wished to make was the need for recognition of time-stratigraphic units—material stratigraphic units comprising the sediments deposited during given time intervals, bounded only by time lines and independent of lithologic or paleontologic facies—as distinct from lithologic units on the one hand and time units on the other. The second point which they wished to make was the desirability of adopting the term *stage* as a fundamental time-stratigraphic unit in regional stratigraphy. *System* and *series* are time-stratigraphic units and their significance in general appears to be clear. However, just as they are indispensable terms in world stratigraphy so also it is of equal importance in intra-regional stratigraphy to recognize time-stratigraphic divisions of lesser rank. The term *stage* has been used in Europe since the middle of the last century for time-stratigraphic units subordinate to a *series* and American representatives concurred in the approval of this usage expressed by the International Congress in Paris in 1900. I do not believe that we should necessarily be bound to recommendations made by an International Congress forty years ago but I do believe we should strive towards international uniformity in stratigraphic nomenclature. It is unfortunate that stage has come into use in this country as a *time* term for interglacial intervals, but under the circumstances is it not perhaps too much to ask that the rest of the world should abandon their usage of the word on this account?

The published abstract did not take up the nomenclature of stages but Tomlinson[12] has discussed this matter at some length and is evidently in-

[11] H. D. Hedberg, "Stratigraphy of the Rio Querecual Section of Northeastern Venezuela" (section on stratigraphic principles), *Bull. Geol. Soc. America*, Vol. 48 (December, 1937), pp. 1975–76.

[12] C. W. Tomlinson, *op. cit.*, pp. 2038–41.

clined to favor, where possible, the use of already established names of rock-stratigraphic units for naming minor time-stratigraphic divisions. He points out that after all it is the "class noun" which indicates to which category any specific unit belongs and that therefore the qualifying geographic name is of significance only in defining the scope of the term regardless of whether it is time-stratigraphic or rock-stratigraphic. I believe that Tomlinson would in general agree with the writer's recommendation that "a stage should, where possible, be based on the well-defined type section of a marine fossiliferous formation (or group) and should bear the name of that formation."[12] Kleinpell and Schenck, on the other hand, have in their usage favored independent geographic qualifying names for time-stratigraphic and for rock-stratigraphic units. Both viewpoints have considerable merit and furthermore I believe they can be satisfactorily reconciled with each other.

I believe that the term *stage* achieves the greatest value and usefulness if it is used as a rather flexible time-stratigraphic term of minor rank, in general subordinate to the *series* terms in any particular region but not necessarily an integral part of a series. I do not believe that the stages within any particular series need necessarily add up in time value to the total time value of the series. In other words, the component stages of a series may overlap, depending on the bases used for their definition and the particular time interval to which they refer, just as a formation may be divided into lithologic units such as claystones, sandstones, red beds, green beds, arkosic beds, carbonaceous beds, *et cetera*, and due to the overlap of classifying characters the sum total thickness of all these divisions will greatly exceed the total thickness of the formation. I should say that the stage divisions of a series may be based on *any* recognizable divisions of the stratigraphic column comprising the series which it is desirable to use as measuring sticks or reference units for indicating relative time-stratigraphic position with respect to the various other stratigraphic sections which may be found in this series.

Fossils constitute one of the most useful means (but not a perfect means) of dating sedimentary rocks and if widespread natural "breaks" in the evolutionary sequence of life forms (independent of local paleontologic facies changes) are found in the sediments composing a series these indeed make desirable stage divisions. Such stages are comparable to those set up by Kleinpell and Schenck and if their limits do not coincide with those of other stratigraphic divisions I believe it is highly desirable and useful to give them new and independent geographic names. At the same time, formations are fundamental and familiar stratigraphic units with which we deal every day in stratigraphic work and it is obviously of great importance to refer to one section in terms of time equivalence to the formations (or other rock-stratigraphic units) of another section. Moreover, it not infrequently happens that certain lithologic features, reflecting climatic conditions or composition of sea waters, for instance, have as much or more time significance with respect to the sediments of a region than do the fossils which these sediments contain and that they consequently have equal or greater value as bases for time-stratigraphic divisions than do fossils. I am therefore certainly opposed to *confining* the criteria for stage division to paleontology. On the contrary, I believe that it may frequently be desirable to use lithologic formations, groups, or members as the bases for stage divisions and I also believe that

[12] H. D. Hedberg, *op. cit.*, p. 1976.

it is frequently desirable and feasible to use time-stratigraphic subdivisions in series which are essentially non-fossiliferous throughout a whole region.

Naturally the formation as an abstract rock-stratigraphic term has no direct time significance. It is a lithologic or lithogenetic unit and its deposition may represent a long or a short time interval, and its age and time scope may change from place to place. However, any *specific* formation has a time value —the time interval from the moment deposition started to the moment when it ceased—and the sediments deposited in a region during the time interval represented by the Socorro *formation*, for example, belong to the Socorro *stage* regardless of lateral lithologic gradation into other formations. In this connection distinction should be made between the Socorro stage (the sediments represented by the interval required for the deposition of the Socorro formation as a whole) and the *type* Socorro stage (the sediments deposited during the interval represented by the type section of the Socorro formation). The important point in setting up a time-stratigraphic division is the *definition of the sedimentary section considered as the type for the unit*, be it rock-stratigraphic or bio-stratigraphic.

The objection may be raised that the procedure outlined above would lead to a confusing number of stages. However, I believe that the differential utility of the many possible time-stratigraphic divisions which could be made would itself automatically take care of this difficulty. Obviously, certain stages, based on either bio-stratigraphic or rock-stratigraphic units, would be found more useful than others for reference and comparison. These would gradually become established as major reference stages through their more widespread usage, in contrast to others for the scope of which there would be need only in special cases. It is doubtless in this manner that many of the principal reference stages of European stratigraphy were developed. Originally they were local lithologic units or units based on sedimentary cycles but through fossil content or other distinguishing characters they were found particularly useful in dating strata in other areas and thus gradually took on time-stratigraphic significance.

It has been said that the use of formation names for stages would lead to confusion between the rock-stratigraphic and time-stratigraphic concepts. On the contrary I am inclined to believe that much of the present and past confusion in this respect has resulted from the failure to use a time-stratigraphic term, such as *stage*, when referring to the time-equivalent of some formation. Too frequently when geologists say that certain beds belong to this or that formation they actually mean the time-equivalent of the formation. If the term *stage* were in common use so that geologists would be accustomed to indicating whether they meant Socorro *formation* or Socorro *stage*, for example, I believe that much confusion would be eliminated. I agree with Tomlinson that the use of the suffix "ian" on stage names is rather unnecessary.

The magnitude of a stage may desirably be left indefinite, just as the magnitude of a series or a system is indefinite, except that stages within a certain region should be subordinate in rank to the series of that same region. Time-stratigraphic divisions of lesser rank than a stage may be called *sub-stages*. The term *zone* was sanctioned by the International Congress in Paris in 1900 as a subdivision of a stage but in the interests of clarity it would seem preferable to use sub-stage. Zone has been employed so widely and loosely that it

is desirable to qualify its use in stratigraphic terminology by a more specific prefix, as *fauni*-zone, *bio*-zone, *mineral* zone, etc.

Certainly a clear distinction should be made between bio-stratigraphic units and time-stratigraphic units, just as the distinction should be made between rock-stratigraphic units and time-stratigraphic units. The principal unit in the bio-stratigraphic category is the *fauni-zone*,[14] which has been defined as a bed or group of beds characterized by an assemblage of organisms, one of which is chosen as index species (or index genus) and gives its name to the unit although it need not be confined to this unit or found in every part of it. A companion term is the *bio-zone*, which is constituted by the strata deposited during the life duration of any particular species. Bio-stratigraphic divisions (as also rock-stratigraphic divisions) may serve as the bases for time-stratigraphic units but strictly in themselves they are not time-stratigraphic divisions. The time value of fauni-zones may fluctuate from place to place with faunal facies variation in much the same manner as the time value of a formation and the time value of a bio-zone may vary with the area or region under consideration. Moreover, a zone (bio-zone or fauni-zone) may be extended appropriately only to the limits of the occurrence of the characteristic species or assemblage of forms on which it is based, regardless of the continuance laterally of sediments of the same age but with different fossil content. Obviously, any number of fauni-zones and bio-zones may be established with any number of overlapping time values depending on the group of fossils under consideration and the species chosen within this group. Only rarely will there be a sufficient concentration of individual bio-zone limits throughout all groups of organisms at any particular time horizon to allow anything but a rather arbitrary choice of bio-zones to be used as a basis for time-stratigraphic divisions of lesser than series rank.

C. W. TOMLINSON, Ardmore, Oklahoma (January 9, 1941).—Much correspondence and other unpublished material was solicited and digested in 1939–40 by this Association's subcommittee on the Permian. My discussion, "Technique of Stratigraphic Nomenclature," published in the *Bulletin* for November, 1940, was founded largely on that material. It seemed only fair to the authors of such unpublished material to refer to their contributions; although it seemed impracticable to quote all of them in full. This may have resulted, in some passages, in a rather one-sided presentation, expounding my own point of view more fully than that of the authors to whom reference was made. For that reason I am very glad that the editors of the *Bulletin* are publishing the foregoing discussions by some of those authors.

The letter signed by members of the geological seminar of Stanford University was written prior to my comment published last November, to which reference may be made for discussion of that letter.

Dr. Hedberg's comment was written later. It includes valuable clarification of several points of stratigraphic usage. His description of the most desirable type section for a stage, if the latter term is to be perpetuated in a time-stratigraphic sense, is excellent, as are also his amplifying statements of the applicability and relative usefulness of paleontological, diastrophic, and lithologic data in that connection. His review of various types of zones is a clear exposition of much current usage.

[14] For a discussion of zone terms see W. J. Arkell, *The Jurassic System in Great Britain*. Clarendon Press (Oxford, 1933).

A novel contribution to the current discussion appearing in Dr. Hedberg's comment is his recommendation for highly flexible use of the term stage, which would even permit successive stages in a single province to overlap one another in time span—a liberty hitherto not generally granted for other time-stratigraphic units. Systems were formed within periods which have not been conceived as overlapping in time. The series described within a system within a given region have likewise generally been regarded as representing epochs, each of which followed the preceding one without overlap. Provincial series units in common use in one part of the world have not in all cases agreed in time-span with series called by different place names, recognized in the same system in other provinces. But there has been a tendency—probably commendable—to work toward a worldwide set of non-overlapping series terms as correlations improved. Should not the same goal be recognized as desirable with stages, even though more flexible and complicated local usage has to be permitted as a temporary makeshift, and perhaps permanently in some instances?

Another item in the flexibility of usage proposed by Hedberg for the term stage is his differentiation between "Socorro stage" and "type Socorro stage," to cite his own examples. The time-span of the "type Socorro stage" would be entirely included within that of the "Socorro stage," the former being defined as comprising all sediments deposited in the same time-span as the type section of the Socorro formation, whereas the "Socorro stage" would include all sediments deposited within the time-span represented by all parts of that formation. In many instances there would be little difference between these two concepts of stages definable from a single formation, but in others (where no single type section could be found representing the whole span of time occupied by deposition of all the sediments described under one formation name), there would be considerable discrepancy between these two stages called by the same place-name. These alternative or complementary concepts amplify the proposal (*cf.* Sutton, *Bull. Geol. Soc. America*, September, 1940) for correspondence in time-span between formations and stages. But such double usage would be incompatible with the ideal of a sequence of non-overlapping stages. Which would be more useful?

Hedberg says that "The magnitude of a stage may desirably be left indefinite, just as the magnitude of a series or a system is indefinite, except that stages within a certain region should be subordinate in rank to the series of that same region." However, since the terms system, series, and stage indicate relative rank (magnitude) of the corresponding units, it would seem desirable to work toward a goal of general, instead of only local, consistency in the use of the same term for stratigraphic units of a given magnitude. Surely it is not actually preferable that some series should exceed other systems in magnitude or that some stages (in the sense here under discussion) should exceed other series. Absolute uniformity probably is out of the question; but may not a defined *range* of magnitude be possible for each term? The respective ranges probably will have to overlap to some extent during the rapid growth of stratigraphic science—but they need not overlap through each other's whole extent. For this purpose magnitude probably should not be defined by thickness of sediments alone, but with regard also to duration of time, and to distinctiveness of boundaries and of paleontological and lithologic content and of diastrophic record.

J. E. EATON, Los Angeles, California (January 23, 1941).—Hedberg cites early ideas of mine[15] which have undergone modification. In these earlier days appreciable stratigraphic successions of less than epoch and series rank were commonly designated by the one term formation, which is basically a physical term. Formations were popularly supposed to be physical units laterally that at some chosen line were separated from an adjacent physical unit in a manner whose mechanics were unexplained. My basic thesis was that lateral gradation is normally progressive, that if we could see all of a blanket deposited in one connected sea under one general control we could nowhere divide it areally, and that the many supposed physical units commonly set up laterally in such a blanket result from seeing disconnected parts of one areally grading whole. I still hold this particular view.

Because the term formation was then the only official one in this country by which to designate both physical and time divisions of less than series and epoch rank, I advocated its use for an entire blanket when there was sufficient evidence to bridge lateral gaps. I have since concluded that such a practice, however theoretically attractive, is not practical, and have adopted the time term *stage* to complement the physical term *formation* somewhat in the manner of larger pairs such as period and system, epoch and series. For the past several years, I have applied the term formation to physical unities over the area such unity can be traced, and the term stage to the time span of an important formation extended over a provincial blanket where supposedly contemporaneous but isolated exposures must be correlated by fossil or other evidence not physically continuous. In so doing, I admit of any number of equivalent or partly equivalent formations in a province, but of only one set of standard marine stages for that province, which standard marine stages theoretically do not overlap one another in time, and add up to the next larger time unit, an epoch, as the epoch is conceived of in the particular province. A separate set of continental stages could be erected which might not individually match the marine set but which would theoretically also be consecutive and add up to some conception of an epoch. I hold with Tomlinson[16] and Hedberg that to require formation and stage names to be necessarily different would result in a needless handicap, and that the suffix *ian* is an optional ornament. With them, I consider that to base a stage on the type fauna and name of some classic or well established formation or group, and use the respective class nouns *stage* and *formation* to distinguish between time and rock usage, is a distinct advantage.

Complementary time and physical terms such as period and system, epoch and series, have long been in use. Need for the next smaller time term, *stage*, to designate laterally the time span of the more important formations or groups in a province, has become apparent. (There seems at present insufficient evidence to use the ideal of one set of world-wide stages in more than a very approximate way.) Need for a time term smaller than epoch is growing as the complicated nature of lateral gradation and lenticularity, both physical and faunal, becomes better known. Increasing confusion has resulted from delay, and is now becoming acute. What is delaying general adoption of the time term *stage?*

[15] J. E. Eaton, "Time Equivalent versus Lithologic Extension of Formations," discussion, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 10 (October, 1932), pp. 1043–44.

[16] C. W. Tomlinson, "Technique of Stratigraphic Nomenclature," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 11 (November, 1940), pp. 2038–46.

Though there are other reasons, I consider the chief one to be that some of various geologists seeking to introduce the term *stage* have been unwilling to let this term take its place simply and normally with other time terms, but have insisted that it be given special dispensations, such as the privilege of ignoring common-law priority, and of necessarily having private place-names. They use the term as a lever by which they would spring into official nomenclature ideologies that, whatever their value may be, are unnecessary to adoption and practical use of the term. Geology has become so complicated a science, with so vast a number of departmental customs, that a few simple master rules which coördinate the whole are vital and have long been in force. First among these master rules I am inclined to put the rule of priority, with the rule that a part shall be compatible with a whole not far behind. Responsibility to geology in general—the immense nomenclature, countless data classified thereunder, and complex inter-relations—is to be considered when adopting important new terms. This is particularly true as regards official bodies, which tend to be cautious and to require that new terms shall respect prior rights and have few special privileges.

Tomlinson,[17] in a recent paper, has provided the first basis for an understanding that has come to my notice. Open-minded toward time terms, he goes directly to the crux of the matter, which is the privileges asked by certain factions. He calls attention, point by point, to the way in which various proposed time schemes diverge from the ideal of maximum coöperation with other geologic data than they employ, to the duty of official bodies to consider the effect on a whole, and the advisability of avoiding special conditions where such would needlessly complicate the record.

Hedberg has now come forth with an outline which avoids some of the objections advanced by Tomlinson and other cautious commentators. He would follow the generally accepted custom of having time and rock data work in the closest possible coöperation. He would not complicate the record with separate, duplicate sets of type sections and names, but would where possible base a stage and its name on the well-defined type section of a fossiliferous formation or group, and distinguish between time and rock usage by the application of different class nouns.

On the other hand, Hedberg favors the word stage for what he calls a "time-stratigraphic" instead of a time term, whereas many, if not most geologists think of it in the latter sense, as an unvarying time unit during which areally varying physical facies may or may not have been locally laid down. My own usage of the term stage has been strictly as a time unit, conceived to have existed (as time) whether rocks are locally present or not.

Hedberg's idea that stages may overlap in time, and need not add up to the next larger time value, appears to me particularly fatal to their useful application. I can understand preliminary, competing stages within a province overlapping one another in time, and stages erected in one province not matching those erected in another due to the present very approximate nature of world-wide correlations. However, it seems to me that the standard time column as conceived of for any one province should have one set of standard, consecutive stages in which individual conflicting stages have been restricted or expanded so that there is at least theoretically an absence of overlap, and that these stages should add up to the next larger time value *as conceived of in that province*. To me, the great value of stages is, that

[17] C. W. Tomlinson. *op. cit.*

though their theoretically exact time boundaries tend to be misdrawn laterally due to ecologic change which results in homotaxial correlations (they vary widely in practice due to ecology), stages defined as time units give us at least the hope of charting time lines through a maze of lenticular, overlapping physical facies. The idea of time planes represents an ideal in a mad jumble of overlapping physical lenses. If we are to abandon this ideal, and have the stages within a province overlap in the same mad way, then I can see little reason for erecting stages.

Opinions differ regarding a preferred definition for time terms smaller than an epoch. It is my personal belief that such terms, if and when officially adopted, should for purposes of maximum coöperation, efficiency, and simplicity, conform as nearly as possible to standard practice for the larger units, which is to base a standard time term on the fauna or flora of a standard physical section and have both carry the same place name and be differentiated by different class nouns. The views of Tomlinson in his paper cited herein appear to provide the closest approach to standard practice that I have thus far seen.

C. W. TOMLINSON, Ardmore, Oklahoma.—Eaton indicates a desire to use the term "stage" for the time in which a certain sequence of rocks was deposited, rather than for the rocks themselves. This usage would differ less than that advocated by Schenck *et al.*, from the present American use of the term in connection with Pleistocene glaciation (e.g., the Wisconsin glacial stage). In Eaton's proposed usage, rocks which Schenck might speak of as *constituting* the Wolfcamp stage, would have to be described as *deposited during* the Wolfcamp stage, or as "rocks of Wolfcamp age." Consistency will be at least technically violated if *stage* is continued as a unit of time in Pleistocene terminology, but is applied as a unit of rocks elsewhere. If either usage persists, it would avoid confusion if the other could be dropped.

R. T. WHITE, Bakersfield, California (March 11, 1941).—The distinction between rock-stratigraphic and time-stratigraphic units has long been recognized. However this distinction in numerous instances has not been explained adequately, and from its lack of application in many publications it is evident that it is not completely understood by a large number of stratigraphers. It is my belief that the lack of understanding of these principles is the result of the loose usage of terms employed in stratigraphic nomenclature, the fact that there is still a controversy over the use of some of the terms, and their relationship to each other, and the fact that many stratigraphers have not been trained to recognize the fundamental differences and their applicability.

Schenck, Hedberg, and Kleinpell in the abstract, "Stage as a Stratigraphic Unit,"[18] have pointed out the fundamental differences between rock-stratigraphic units (formations) and time-stratigraphic units (stages, zones, *et cetera*). Since formations and stages are fundamentally different entities, every precaution should be taken against confusing the two terms.

It is my belief that the differences in the meaning of these two terms can be emphasized by applying a place name to a stage different from that of any

[18] H. G. Schenck, H. D. Hedberg, and R. M. Kleinpell, "Stage as a Stratigraphic Unit" (abstract), *Geol. Soc. America Proc. 1935* (1936), pp. 347–48; *Amer. Geol.*, Vol. 64, No. 1 (1934), p. 70. See footnote 8 in discussion by H. D. Hedberg in this volume.

formation embraced by it. Further, it is my belief that the addition of the suffix *ian* to stage names is of real advantage. Admittedly, such an expression becomes adjectival in form, requiring for completion a class noun, expressed or implied. However, if the qualifying noun, stage, is not expressed, it is implied and there is no possibility of confusion with the word formation. In the event the boundaries of a formation should happen to correspond with those of a stage, and the two are designated by the same name, the suffix *ian* would distinguish them. If this were not done the distinguishing class nouns, formation or stage, would have to appear after each use of the place name to avoid any possible misinterpretation.

It seems to me that the use of the same place name for both a formation and a stage conveys a similarity of meaning between the two terms that is not warranted. The fact that formations are sometimes restricted or redefined on the basis of faunal criteria to correspond with the limits of the "stages" named after them is evidence that the true distinction between rock-stratigraphic and time-stratigraphic units has not been clearly understood.

The relative magnitude of stages as compared to series and all the criteria by which stages are delimited will be subjects of debate for a long time to come. However this should not prevent our adopting means of differentiating more clearly between time-stratigraphic and rock-stratigraphic units. The use of place names for stages different from those of formations, or at least the use of the suffix *ian* for stage names, will be an aid in that accomplishment.

WELL LOGGING BY RADIOACTIVITY[1]

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In a recent paper,[3] two radioactivity logs in Lea County, New Mexico, are shown in Figure 4. R. K. DeFord has recently called the writer's attention to the fact that the section between the Rustler and the Capitan is now preferably called "Salado" instead of "Upper Castile."[4,5]

DeFord's investigations also show that the Rustler formation in Well C, Figure 4, extends from 1,175 to 1,550 feet and in Well B from 1,160 to 1,565 feet.

[1] Manuscript received, November 20, 1941.

[2] Geologist, Well Surveys, Inc.

[3] William L. Russell, "Well Logging by Radioactivity," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 9 (September, 1941), p. 1786.

[4] Walter B. Lang, "Salado Formation of the Permian Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 10 (October, 1939), pp. 1569–72.

[5] Ronald K. DeFord and E. Russell Lloyd, "West Texas-New Mexico Symposium: Part I. Editorial Introduction," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), p. 11.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 12 (DECEMBER, 1941), PP. 2212-2215

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and available, for loan, to members and associates.

INTRODUCTION TO PHYSICAL GEOLOGY, BY W. J. MILLER

REVIEW BY HERSCHEL L. DRIVER[1]
Los Angeles, California

Introduction to Physical Geology with Special Reference to North America, by W. J. Miller. 465 pp., 397 text figs. D. Van Nostrand Company, Inc., New York (1941). Fourth edition. Price, $3.25.

The most conspicuous change between this fourth edition and the previous edition is that the physical and historical portions now appear in separate volumes instead of being combined into one volume. The more recent edition is larger than the portion allotted to physical geology in the third edition, for there are thirty additional pages of text, forty-six additional figures, and the page size has been increased from 5 inches by 8 inches to 6 inches by 9 inches. Some portions of the text have been revised and rewritten. A good grade of paper has been used which permits excellent reproduction of the many well selected photographs used for illustration.

The work is logically grouped into fifteen chapters. The first chapter deals with the earth as a planet, geological time, and defines the branches of geological science. The next chapter deals with diastrophism and earthquakes. Materials of the earth; weathering; structure of the earth's crust; the work of streams, glaciers, wind, and sea; volcanoes; subsurface water; mountains; plateaus; plains; and lakes are discussed in sequence in succeeding chapters. The last chapter deals briefly with economic phases of coal, petroleum, natural gas, and some metals and rocks. These chapters are followed by an appendix in which the essential properties of thirty-nine common and useful minerals are noted. A detailed index completes the volume. Physical geology is presented in a readily understandable manner and is illustrated by references to numerous appropriate examples and excellent figures. One comparatively minor defect is the almost total absence of references to recent publications in the list of selected references. The text should be popular with students and will serve as a convenient reference book on physical geology.

[1] Standard Oil Company of California. Manuscript received, October 23, 1941.

RECENT PUBLICATIONS

ALBERTA

*"Alberta Basin Becomes Important Factor," by Frank R. Henry. *Oil Weekly*, Vol. 103, No. 8 (Houston, October 27, 1941), pp. 40–42; map, sections, and stratigraphy column.

*"Preliminary Map, Morley, Alberta," by G. S. Hume and H. H. Beach. *Canada Geol. Survey Paper 41–8* (Ottawa, 1941). Areal, structural, and topographic sheet, showing Cambrian, Devonian, Carboniferous, Jurassic, and Cretaceous. Topographic contour interval, 100 feet. Scale, 2 inches = 1 mile. Size, 33 × 42 inches. Price, $0.10.

*"Preliminary Map, Bighorn River, Alberta," by B. R. MacKay. *Canada Geol. Survey Paper 41–9* (Ottawa, 1941). Areal, structural, and topographic sheet, showing Devonian, Carboniferous, Triassic, Jurassic, and Cretaceous. Topographic contour interval, 100 feet. Scale, 2 inches = 1 mile. Size, 27×40 inches. Two structure sections on separate sheet, 37×14.5 inches (scale 2 inches = 1 mile). Price, $0.10.

*"Preliminary Map, Redcliff, Alberta," by J. S. Stewart. *Canada Geol. Survey Paper 41–11* (Ottawa, 1941). Areal map, showing Upper Cretaceous. Size, 16.75×20.75 inches. 3 mim. pp., description.

CALIFORNIA

*"Southern San Joaquin Valley, California," compiled by *Oil and Gas Jour.*, Vol. 40, No. 25 (Tulsa, October 30, 1941). 2 pp. between pp. 40 and 41; sketch map and 2 geologic sections in color.

CANADA

*"Mineral Industry of the Northwest Territories," by C. S. Lord. *Canada Geol. Survey Mem. 230* (Ottawa, 1941). 136 pp., 9 figs. Petroleum and natural gas, p. 28. Price, $0.50.

FLORIDA

"Peninsular Oil and Refining Company's J. W. Cory No. 1." *Florida Geol. Survey Bull. 19* (Tallahassee, August, 1941). Study of cuttings and core from well near Pinecrest, Monroe County. Postage, $0.06.

"A Fossil Squirrel-Fish from the Upper Eocene of Florida," and "The Rostrum of Felsinotherium Ossivalence." *Ibid., Bull. 22.* Postage, $0.03.

GENERAL

*"Effects of Sand Grain Size Distribution upon Porosity and Permeability," by Wilbur F. Cloud. *Oil Weekly*, Vol. 103, No. 8 (Houston, October 27, 1941), pp. 26–32; 6 figs.

*"Scope and Content of the Petroleum Engineering Curriculum," by Lester C. Uren. *Amer. Inst. Min. Met. Eng. Tech. Pub. 1350* (1941). 8 pp., 3 tables.

*"Further Advances in Prospecting by Electric Transient," by Gifford E. White. *Ibid., Tech. Pub. 1389* (1941). 9 pp., 9 figs.

*"A Study of the Problem of Depth Determination by Means of Earth-Resistivity Measurements," by William A. Longacre. *Ibid., Tech. Pub. 1392* (1941). 7 pp., 3 figs., 4 tables.

**Influence of Geophysics upon Geology Curricula* (Amer. Inst. Min. Met. Eng., 1941). "Papers presented at two joint meetings of the Mineral Industry Education Division, Geophysics Committee, the American Geophysical Union, and the Committee on College Curricula of the American Association of Petroleum Geologists, at the A.I.M.E. meeting in New York on February 17 and 18, 1941. At the first meeting, the Mining Geology Committee, the Society of Economic Geologists, and the Committee on Applications of Geology of the American Association of Petroleum Geologists also took part."

"Influence of Geophysics and Geochemistry on the Professional Training of Geologists," by W. C. Krumbein. *Tech. Paper 1327.*

"The Education of an Exploration Geophysicist," by M. M. Slotnick. *Tech. Paper 1367.*

"The Nature of Geological Inquiry and the Training Required for It," by Walter H. Bucher. *Tech. Paper 1377.*

"The Place of Observational Geology, Past and Present," by Benjamin L. Miller. *Tech. Paper 1378.*

"Basic Science in Geological Curricula," by H. W. Straley, III. *Tech. Paper 1379.*

"An Arts and Science Curriculum in Geophysics," by J. B. Macelwane. *Tech. Paper 1380.*

"A Geophysics Option in a Comprehensive Earth-Science Curriculum," by H. Landsberg. *Tech. Paper 1381.*

"Discussion on the papers of the Symposium." *Tech. Paper 1382.*

ILLINOIS

"Trenton Production in Illinois," by George V. Cohee. *Illinois Geol. Survey Illinois Petroleum No. 39* (Urbana, September 13, 1941).*" Trenton Lime Production in Five Illinois Pools," condensed by *Oil and Gas Jour.*, Vol. 40, No. 25 (October 30, 1941), from the Illinois Survey report, pp. 164 and 166; 1 cross section.

*"Rural Hill Field (T. 6 S., R. 5 E.), Hamilton County, Illinois," compiled by *Oil and Gas Jour.*, Vol. 40, No. 24 (Tulsa, October 23, 1941), pp. 63–65; 1 development map.

LOUISIANA

*"Ground-Water Resources of Grant and La Salle Parishes, Louisiana," by John C. Maher. *Louisiana Geol. Survey Bull. 20* (Baton Rouge, August 1, 1941). 95 pp., 2 pls., 14 figs., 5 tables.

NEW MEXICO

"Transgressive and Regressive Cretaceous Deposits in Southern San Juan Basin, New Mexico," by J. D. Sears, C. B. Hunt, and T. A. Hendricks. *U. S. Geol. Survey Prof. Paper 193 F* (September, 1941), pp. 101–21, Pls. 25–31, Figs. 20–24. Sold by Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.35.

*"Earth Resistivity as Applied to Problems of Exploration in the Potash-Bearing Region near Carlsbad, New Mexico," by H. Cecil Spicer. *Amer. Inst. Min. Met. Eng. Tech. Pub. 1354* (1941). 10 pp., 7 figs.

OKLAHOMA

"Subsurface Geology and Oil and Gas Resources of Osage County, Oklahoma, Part 7, Townships 20 and 21 North, Ranges 11 and 12 East," by W. R. Dillard, N. W. Bass, and C. T. Kirk. *U. S. Geol. Survey Bull. 900 G* (September, 1941), pp. 237–68, Pl. 7. Sold by Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.30.

"Subsurface Geology and Oil and Gas Resources of Osage County, Oklahoma, Part 8, Parts of Township 20 North, Ranges 9 and 10 East, and Township 21 North, Ranges 8 and 9 East, and all of Township 21 North, Range 10 East," by C. T. Kirk, W. R. Dillard, Otto Leatherock, and H. D. Jenkins. *U. S. Geol Survey Bull. 900 H* (September, 1941), pp. 269–302, Pl. 8. Sold by Supt. Documents, Govt. Printing Office, Washington, D. C. Price $0.35.

"Subsurface Geology and Oil and Gas Resources of Osage County, Oklahoma, Part 9, Townships 23 and 24 North, Range 7 East," by N. W. Bass, W. R. Dillard, L. E. Kennedy, and H. B. Goodrich. *U. S. Geol. Survey Bull. 901 I* (September, 1941), pp. 303–19, Pl. 9. Sold by Supt. Documents, Govt. Printing Office, Washington, D. C. Price $0.25.

ONTARIO

*"Palaeozoic Geology of the Brantford Area, Ontario," by J. F. Caley. *Canada Geol. Survey Mem. 226* (Ottawa, 1941). 176 pp., 3 maps folded in pocket. Price, $0.50.

TEXAS

*"Upper Gulf Coast District—Texas," compiled by *Oil and Gas Jour.*, Vol. 40, No. 26 (Tulsa, November 6, 1941). 2 pp. between pp. 144 and 145; sketch map and stratigraphic column in colors.

TRINIDAD

*"Trinidad Oil," by E. N. Tiratsoo. *Petroleum*, Vol. 4, No. 5 (London, September, 1941), pp. 110–16; 4 figs.

WYOMING

"Geology and Oil and Coal Resources of the Region South of Cody, Park County, Wyoming," by W. G. Pierce and D. A. Andrews. *U. S. Geol. Survey Bull. 921 B* (September, 1941), pp. 99–180, Pls. 11–23, Figs. 10–13. Sold by Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $1.00.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 15, No. 6 (November, 1941).

"Eocene Smaller Foraminifera from the Salt Mountain Limestone of Alabama," by Lyman D. Toulmin.

"The Ostracode Genus *Cytherelloidea* from the Tertiary of the Netherlands East Indies," by L. W. LeRoy.

"A New Species of *Cibicides* from the Lower Pliocene (Repetto Formation) of Southern California," by L. W. LeRoy.

"New Foraminifera from the Denton Formation in Northern Texas," by Don G. Vieaux.

"Bibliography and Index to New Genera, Species, and Varieties of Foraminifera for the Years 1937 and 1938," by Hans E. Thalmann.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 12 (DECEMBER, 1941), PP. 2216–2220, 1 FIG.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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MEETINGS OF SCIENTIFIC SOCIETIES IN DECEMBER

The 54th annual meeting of The Geological Society of America, H. R. ALDRICH, secretary, 419 West 117th Street, New York, will be held December 29–31, at the Hotel Statler, Boston, Massachusetts, under the auspices of the Geological Society of Boston, the Massachusetts Institute of Technology, and Harvard University. The address of the retiring president, CHARLES P. BERKEY, will be delivered on December 29. Associated societies which will hold meetings in conjunction with the Geological Society are the following: The Paleontological Society, 33d annual meeting, secretary, H. E. VOKES, American Museum of Natural History, New York; The Mineralogical Society of America, 22d annual meeting, secretary, PAUL F. KERR, Columbia University, New York; The Society of Economic Geologists, 22d annual meeting, secretary, W. D. JOHNSTON, JR., U. S. Geological Survey, Washington, D. C.; The Society of Vertebrate Paleontology, 1st annual meeting, secretary, GEORGE G. SIMPSON, American Museum of Natural History, New York. The Geological Society of America will join with Section E of the American Association for the Advancement of Science, the Texas Academy of Science, the Dallas Petroleum Geologists, the Fort Worth Geological Society, and the Association of American Geographers in sponsoring the meetings to be held in Dallas, Texas, December 29–31. HUGH D. MISER as retiring vice-president of Section E will deliver the principal address: "Quartz Veins in the Ouachita Mountains of Arkansas and Oklahoma."

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TWENTY-SEVENTH ANNUAL MEETING
DENVER, APRIL 21–24, 1942

A meeting of the executive committee of the Association and representatives of the Rocky Mountain Association of Petroluem Geologists was held at the Cosmopolitan Hotel, Denver, Colorado, on October 25, to make preliminary arrangements for the twenty-seventh annual meeting to be held at Denver, April 21–24, 1942. Those present included the following.

Edgar W. Owen, San Antonio, Texas, president of the Association
Edmond O. Markham, Tulsa, Oklahoma, secretary-treasurer
Walter A. Ver Wiebe, Wichita, Kansas, editor
A. E. Brainerd, Rocky Mountain associate editor
A. I. Levorsen, Tulsa, former president, chairman of the research committee
Charles S. Lavington, Denver, Rocky Mountain district representative
C. E. Dobbin, Denver, Association representative-at-large
Ninetta Davis, president, Rocky Mountain Association
Margaret F. Boos, University of Denver
Ralph Copley, The California Company
C. E. Erdmann, U. S. Geological Survey
Don S. Gould, Colorado College
T. S. Harrison, consulting
C. A. Heiland, Colorado School of Mines
J. Harlan Johnson, Colorado School of Mines
David B. Miller, consulting
Harry W. Oborne, consulting
C. E. Shoenfelt, consulting
R. E. Spratt, U. S. Geological Survey
Warren O. Thompson, University of Colorado
John W. Vanderwilt, consulting
F. M. Van Tuyl, Colorado School of Mines
W. A. Waldschmidt, Colorado School of Mines

The following committee chairmen and representatives have been appointed to arrange for the convention program and activities.

General	C. E. Dobbin, U. S. Geological Survey
Technical program	A. E. Brainerd, Continental Oil Company
Finance	Hugh A. Stewart, The Texas Company
Entertainment	Harry W. Oborne, Colorado Springs, consulting
Hotels	Charles S. Lavington, Continental Oil Company
Registration	Charles M. Rath, consulting
Field trips	
Western Slope	John A. Vanderwilt, consulting
Front Range	F. M. Van Tuyl, Colorado School of Mines
Reception	T. S. Harrison, consulting
Publicity	W. A. Waldschmidt, Colorado School of Mines
Educational exhibits	Warren O. Thompson, University of Colorado
Society of Economic Paleontologists and Mineralogists	J. Harlan Johnson, Colorado School of Mines
Society of Exploration Geophysicists	F. Goldstone, Shell Oil Company, Inc., Houston, Texas C. A. Heiland, Colorado School of Mines

Geologists of the Rocky Mountain region and their wives were dinner guests of Mr. and Mrs. Thomas S. Harrison at the Cherry Hills Country Club, south of Denver, on November 18. After dinner the ladies played bridge, while the geologists discussed, informally, plans for the A.A.P.G. convention.

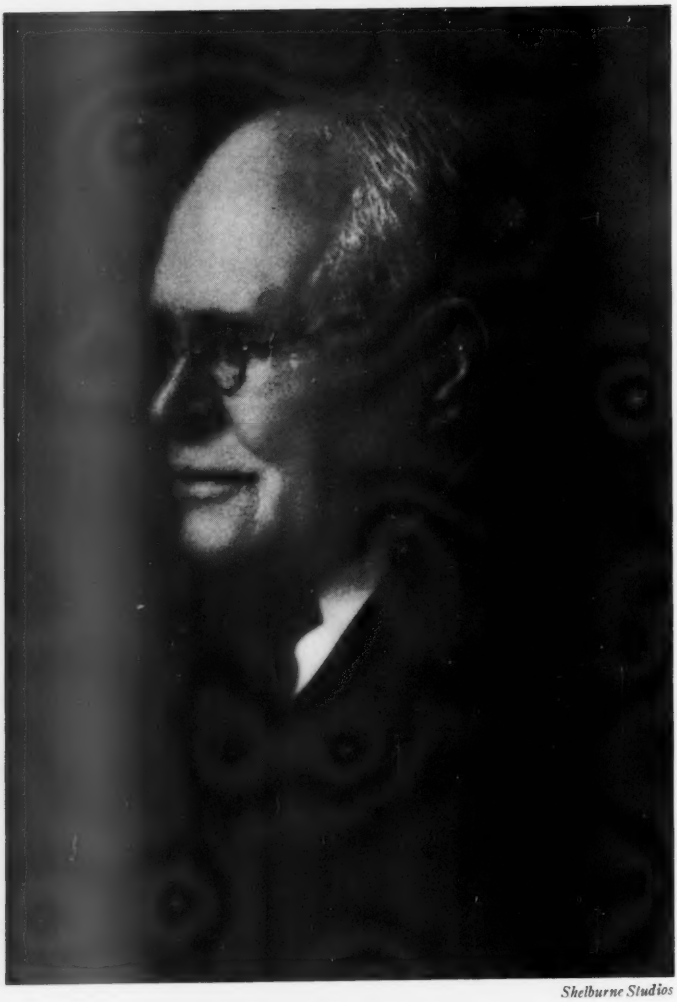
(Van Tuyl and Lovering. Reproduced by courtesy of the Geological Society of America and the Colorado School of Mines.)

PLAINS, FOOTHILLS, AND FRONT RANGE OF THE ROCKY MOUNTAINS

Aerial view looking northwest from a point about 2 miles southeast of the town of Morrison. On the west is the eastern margin of the Colorado Front Range, with Mount Morrison in the left middle distance. The Park of the Red Rocks, whose large east-dipping slopes appear white in the sunlight, lies at the base of Mount Morrison. A remnant of a peneplain appears above and beyond the Park. The pronounced ridge extending northward from the middle foreground represents the Dakota hogback. The sharp notch in this is a water gap cut by Bear Creek. The long narrow hogback reflecting the light in the right middle distance represents an exposure of basal Niobrara limestone. The Colorado School of Mines, at Golden, in the foothills, is shown by the arrow. The Table Mountains are in the right distance, east of Golden.

At the west lies the Colorado Front Range with its wealth of physiographic, igneous, and metamorphic features and rich ore deposits. The foothills are developed on Paleozoic, Mesozoic, and early Cenozoic sedimentary rocks which are steeply upturned along the mountain front as a result of folding and faulting, but are nearly horizontal under the lava-capped Table Mountains on the east, beyond which the Great Plains appear.

This view was taken about 15 miles west of Denver, where the twenty-seventh annual meeting of the Association will be held on April 21–24, 1942, at the Cosmopolitan Hotel.



Shelburne Studios

ROBERT THOMAS HILL

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 12 (DECEMBER, 1941), PP. 2221-2231, 3 FIGS.

Memorial

ROBERT THOMAS HILL
(1858–1941)

With the passing of Dr. Robert Thomas Hill on July 28, 1941, there came to a close one of the most interesting and productive careers in the field of American geology. Born in Nashville, Tennessee, on August 11, 1858, his life span encompassed the most notable epoch in the social and economic development of the North American continent. His experience spanned the wide range from life in an obscure outpost on the edge of the frontier to a place of distinction in scientific circles both at home and abroad. It peculiarly symbolizes the American tradition that native ability, fortified by perseverance and courage, can ultimately win the recognition to which it is justly entitled. His many-faceted interests were shaped and developed in a rapidly changing environment. A rugged physical constitution, the heritage of a strenuous life in the open during his developing years, enabled him to live with gusto, and his keen interest in nature inspired throughout his mature life a notable and significant output of scientific studies covering a wide range of subjects. Much of his geological work was in pioneer fields. It is remarkable that so much of it has withstood the test of time, and has been so little changed by the host of subsequent investigators who have followed in his wake.

His earliest childhood recollections were of war-torn Nashville. The Hill family of father, mother, and eight children was broken up, a casualty of the war, and the members were scattered, some never to see each other again. He was orphaned at the age of five and went to live with other unattached relatives in the capacious home of a grandmother. As soon as he was old enough, he was obliged to do his bit to eke out the scanty family income by taking on a paper route which necessitated arising at two-thirty in the morning in order to be home in time for school.

The atmosphere of post-war Nashville conformed to the traditions of the old South. Though poverty-stricken and embittered by misfortunes, the finer amenities of life were punctiliously observed and a high plane of religious morality prevailed in the homes of the older residents. Here the youngster unconsciously absorbed much of the moral fiber which was to govern his later life, though at the time he was conscious only of being subjected to inhibitions and restraints which served to gall his spirit. Above all, he was supremely lonely. The feeling grew, perhaps unjustifiably, that he was unwanted, and was an unnecessary burden on the family.

At this juncture, when he had finished the sixth grade of school and the outlook seemed darkest to the introspective boy of sixteen, a heaven-sent opportunity was presented to escape from what he then considered the stifling routine of his life in Nashville. An elder brother, who had drifted to far-away Texas to become the first printer at Comanche, at the time the farthest west settlement on the southwestern frontier, invited young Hill to come and live with him. A family council decreed in favor of the venture, and in the fall of 1874 he put forth on a journey into the unknown where he was to experience adventures startling beyond any expectation.

The trip was by train to St. Louis and via Dallas to East Waco, the nearest rail approach to Comanche. The inexperienced boy landed without cash in the midst of a rough, western town, and after several hungry days, made the acquaintance of freighters at a wagon yard, who kindly took him with them to Comanche. Two weeks were required for the hundred-mile trip across blackland quagmires and sand hills, in wet, chilling, winter weather. A Christmas Eve frontier celebration was in progress when he arrived in Comanche and located his brother.

Comanche was a straggling town of stone and log houses in irregular array around the court-house square. Mail was received twice weekly by horseback. The permanent residents were largely drawn from old Milam County and were chiefly kindly, hospitable people of sound integrity; but there was also a floating population of adventurers, gamblers, and questionable characters who clung to the fringes of the frontier and were capable of any lengths of violence and outlawry. The townspeople were constantly on guard to keep this lawless element under control, and the task was far from an easy one. Here Hill was to spend the next seven years of his life, sleeping at night on a pallet spread on the floor of the print shop, patronizing "Uncle Jake" Nabors' dining room, working ten hours per day as printer's devil, and getting the feel of his strange and unfamiliar surroundings.

In Nashville he had lived with a group of elderly women and had become accustomed to lack of youthful companionship. In Comanche he was more than ever forced to rely on himself to occupy his spare time. He read the papers received in exchange by the Comanche *Chief* and thus maintained some contact with the outside world. A youthful arrival had in his luggage a copy of Wilson's *Fifth Reader* which Hill borrowed and read with avidity by candlelight. Prior to reading this book it is doubtful whether he knew of the existence of the science of geology. On Sundays, he made solitary excursions on foot into the country. On one such trip, he located a bed of fossil oyster shells which promptly fired his imagination, and he connived with the local druggist, "Doc" Hamilton, to order him a book on geology, eventually receiving a copy of Dana's *Manual*. Further search revealed a great variety of fossils, for the area abounds in fossiliferous horizons. Hill was thus launched on the beginnings of his geological career.

Frequent opportunities enabled him to explore farther afield. He made occasional trips with visiting drummers from Dallas and Fort Worth who craved companionship in the long intervals between settlements. He made horseback trips to Fort Griffin, then in its heyday as outfitting post for the buffalo hunters, and a notorious hole of frontier iniquity. There he saw General Mackenzie bring in his captive band of Comanches after the battle of Quitaque which finally opened up the western country of Texas to settlement.

In 1876 he was a member of a party sent out to survey lands in the Red Beds country lying between Fort Griffin and the foot of the High Plains. Colonel A. M. Hobby of Galveston, a scholarly gentleman and an amateur naturalist, was leader of the expedition. He took a fancy to Hill and spent much time inducting him into the natural lore of that strange and fascinating country, which was then untouched by the white man, and abounded in buffalo and other wild game. The following year the lonely youth was befriended by Captain Jim Holmsley, a resident cowman of Comanche. He was taken along as cowboy with one of the Holmsley herds and spent six months on the

trail between Uvalde and Dodge City. Though in no sense a cowboy, the trip afforded opportunity to see more of the life of the west and explore a new country. On the way, he encountered the fleeing Cheyennes who were rebelliously returning to their native northern plains after a brief sojourn in the unfamiliar Oklahoma reservation to which they had been removed by the Government. Incidentally, he recalled mirthfully that this episode gave him one of the worst scares he had ever experienced. Later, at Fort Elliott, he saw the frontier cavalry of the army in action, a colorful scene which made an indelible imprint on his memory.

Thus he came to know and love the country which was henceforth to be the scene of a substantial part of his significant contribution to the science of geology. In this frontier experience during his impressionable youth lies the explanation of his intense love and understanding of nature which is reflected in his popular writings; his interest in surface topography which presaged his later skill as a geographer; his interest in Indian lore; and finally, his burning interest in rocks and fossils which led him eventually into geology as a profession.

Hill's interest in geology aroused comment among residents of Comanche. One day a friendly Swiss barber suggested to him that somewhere it should be possible for one so keenly interested in rocks to learn more about them—that he should write a letter of inquiry to one of the papers for such information. The suggestion was followed and Hill addressed the letter to Garrett P. Serviss, science editor of the New York *Sun*. He was kindly referred to Andrew D. White, president of Cornell University, which made liberal entrance exceptions in favor of students who were lacking in formal education. Dr. White invited Hill to come to Cornell and bring along his collection of fossils. Hill succeeded in borrowing money for the trip from a friend, and the invitation was accepted.

In March, 1882, he again entered a strange world, as different from the raw life of the frontier as it had differed from life in the Blue Grass country of Nashville. Here a world of academic freedom, devoid of any taint of sectionalism, where one could voice any honestly held opinion without fear of ostracism. Again without funds, he became a handy-man about the university, setting type in the print shop, mowing professors' lawns, cleaning laboratories, living meanwhile in a garret room to minimize expense. All hardship was, however, more than compensated by the privilege of devoting himself to serious and systematic study. Not too much formal geology was then taught at Cornell, but he found inspiring leadership in Henry S. Williams, professor of paleontology, who encouraged him to compile the material which was later published as *Bulletin 45* of the United States Geological Survey. He also delved extensively into collateral branches of natural history, following the natural bent of his youth. Because of meritorious progress in geology, he was granted his diploma on the completion of approximately three years' work. Here he formed an abiding friendship with a classmate, David White; and here they both met their future wives, who were also intimate friends.

The young graduate was now qualified to start his life's work in his chosen field, and on the recommendation of Professor Williams, he was appointed assistant paleontologist in the National Museum at Washington at a salary of $50 per month. Soon thereafter he was made assistant geologist on the newly established Geological Survey, and there came under the leadership of John

W. Powell, the director, who was a capable administrator and a noble personality. Major Powell was henceforth to be a prime factor in shaping Hill's career. Because of Hill's knowledge of the Cretaceous, he was sent to Arkansas to assist J. C. Branner in a study of the Arkansas Cretaceous. Malaria almost brought his geological career to an untimely end, and the final report had to be completed by others. Major Powell next sent him, in 1887, to Texas to take steps leading to the organization of a State geological survey. After various mishaps, this effort resulted in the desired end and E. T. Dumble was chosen director. Meanwhile, Hill was offered the opportunity of establishing a chair of geology at the University of Texas, which he accepted with enthusiasm and entered on his duties at Austin in the fall of 1888. He was overjoyed at being back among old friends with the privilege of working in what he considered one of the greatest field laboratories of geology in the world. His professorship at the University lasted only two years. He found conditions not entirely to his liking and resigned to return to Washington. Before returning there in 1890, he continued his studies of the Cretaceous section along the Colorado River, particularly in the vicinity of Austin, and the results of his investigations were set forth in a series of six papers published contemporaneously. He also visited northeast Texas and southern Oklahoma to gather data on the Cretaceous strata lying between central Texas and Arkansas, provinces with which he was familiar.

His next assignment was an investigation of underground waters in Texas, New Mexico, and Indian Territory under the auspices of the Agricultural Department. This gave him opportunity to study the Cretaceous over a wider field and to observe the physiographic features of the region. Hill considered the deductions made during this study among the most important of his career. The organization of the supervising departmental body had been hastily accomplished and it was apparently none too efficient. His final report was hurriedly and carelessly printed and contained numerous typographical errors which interfered with its interpretation. This led to most unfortunate results for Hill. It laid him open to attack for careless work, and he was greatly chagrined when the priority of his work was questioned as a result of the delay in issuing a second, corrected version of the report in 1892.

Then he returned to Washington to become secretary to the Committee on Irrigation of Arid Lands of the 52nd Congress. This task was more or less of a sinecure, but it gave Hill ample time and office space in which to lay the groundwork for his future Black and Grand Prairie report and the Physiographic Atlas of Texas.

In 1892, he returned to the Geological Survey, first, as executive officer, and later, as one of its four principal geologists. Back once more under Major Powell's kindly direction, he entered pleasurably on ten years of his most productive work. During summers he prosecuted his studies of the Texas Cretaceous with the greatest personal freedom of movement; during winters he carried forward studies in the Caribbean under the direction of Professor Alexander Agassiz of the Museum of Comparative Zoölogy of Harvard University. The Caribbean research led eventually to publication of a series of reports on Cuba, Porto Rico, Jamaica, Panama, and Costa Rica. A summary report on the Windward Islands was completed but never published.

During this period he entered extensively into the scientific and social life of the Capital. He formed numerous lasting friendships among leading men in

government and scientific circles; frequented the Cosmos Club, which was then, as now, a rendezvous for men in all branches of science; made numerous trips to Europe, Mexico, South and Central America.

It is unnecessary to detail more fully the various researches of this period. Suffice it to say that he completed the Austin folio in which he interpreted to his satisfaction the stratigraphic sequence of the strata and unraveled the intricacies of the Balcones Fault zone; the Black and Grand Prairie report; the study of the Edwards Plateau region; the Physiographic Atlas of Texas. He explored the canyons of the Rio Grande in the autumn of 1900, and in May, 1901, he joined a party of geologists and geographers to study the eruption of Mont Pelee in the island of Martinique. He spent three seasons in a study of trans-Pecos Texas and compiled voluminous data which remain in manuscript.

Meanwhile, Major Powell had died, and succeeding changes in the administration of the Geological Survey did not meet with his approval. He decided to retire from the Survey and take up his residence in New York to follow consulting work in mining geology. This period of his life (1902–1912) seems to have left a bitter taste in memory, and he seldom made reference to it in his personal writings. He was engaged in various mining ventures throughout the Southwest and in Mexico. Several times a fortune seemed to be within his grasp, only to fade out disastrously. He was chagrined not only by losing money himself but by losing that of friends and relatives. He finally concluded that various of his associates were using his name and prestige to gain favor for their nefarious ventures. The conviction settled on him that he was not qualified for commercial work—that his chief interest lay in the field of science; and henceforth, aside from various consulting assignments in the field of dam construction, and a brief period of oil consulting practice in Texas, he devoted his later years to delving into varied scientific investigations, with scant thought of the monetary compensation involved.

About 1912, he went to California which was home for the next eighteen years. For a time he was consultant to the Board of Water Engineers of Los Angeles County. He made extensive studies of the geology of Southern California and the Los Angeles City region on both of which he prepared unpublished reports. He extensively explored the earthquake problem of California and published a volume on the subject. He was attached to the staff of the Museum of Los Angeles for several years, and taught for one year at the University of California, Los Angeles Branch. From 1917 to 1922, he spent much of his time in Texas as a consultant on oil, maintaining a residence in Dallas and several offices. During this period fortune again favored him, and he succeeded in recouping his finances.

For many years he longed to return to Texas. On each succeeding visit this desire was whetted, and he frequently expressed the wish to spend his declining years among his old friends. In March, 1931, this desire was fulfilled. Through a lifelong friendship with George B. Dealey, publisher of the Dallas *News*, Dr. Hill was engaged to write articles for the *News*, dealing with the geology and oil resources of Texas. The East Texas field was in its early development and the geology of oil was much in the public mind. Dr. Hill brought to his newspaper work great prestige as a geologist, and through his *News* articles he rapidly developed into an institution. He gradually broadened the scope of his articles to cover the numerous fields of his scientific interest,

and not infrequently indulged in personal reminiscence and comment on current events. He devoted his geographic talent and his intimate knowledge of the topography and resources of the Southwest to an interpretation of the routes of the early Spanish, French, and Anglo-American explorers and brought to light numerous overlooked or misinterpreted facts. In short, for the first time in his life, he had full license and opportunity to write to his heart's content on the multiple interests of his colorful and diversified career. And the reading public responded nobly, as is evidenced by the numerous scrapbooks throughout the Southwest which are repositories of his articles clipped from the *News*. He retained to the last a marvelous facility of memory, a twist for humor, and his friends regret only that he did not find time to write more of the personal experiences which he was capable of retailing with zest and fidelity. When pressed to do this, his usual retort was that he objected to "old women's back-stairs gossip," which he considered beneath his standing as a scientist. Thus was lost to the public a great fund of anecdotal material which is warp and woof of the history not only of the Southwest, but of the entire country. It should promptly be added in extenuation, however, that we should be grateful for the prodigious mass of material published by the *News*, which Dr. Hill prepared under the greatest physical handicap—declining eyesight in the one remaining eye, defective hearing, physical decrepitude, and recurrent heart attacks. Yet he worked on unrelentingly to the very last, the worn body retaining much of the wonderful resiliency born of years of sturdy life in the great outdoors.

A catalogue of the scientific organizations to which he belonged would be equivalent practically to a roster of the geological and geographical societies of national importance. It would include many of a more local character, and many others in related fields of science. Likewise, the list would include numerous social and fraternal organizations. To mention merely a few, he was an original fellow of the Geological Society of America and past-president of the Cordilleran Section; a founder member of the National Geographic Society; founder and honorary member of the Texas State Historical Association; honorary member of the American Association of Petroleum Geologists (1926); founder member of the Engineers and the Explorers Clubs of New York; and member, since 1891, of the Cosmos Club, Washington, D. C.

His first scientific paper was published in 1886, shortly after his arrival in Washington. Throughout his subsequent life he was a prodigious contributor to geological and geographical journals. Prior to his connection with the Dallas *News* in 1931, he published some two hundred titles under accredited scientific auspices. Meanwhile, he wrote more than fifty articles on geological subjects which appeared in numerous newspapers throughout the country. He insisted that many of these newspaper articles were equally as important as others given more formal publication. In addition, he wrote a number of articles on various subjects for the popular press. During the last ten years of his life he contributed, on the average, one article per week to the Dallas *News*.

He held the degree of Bachelor of Science from Cornell University (1886); Doctor of Science from Southern Methodist University and Doctor of Laws from Baylor University, both honorary; and was joint medallist of the Société Geologique de France.

He was twice married: first to Miss Justina Robinson of Ware, Mas-

sachusetts, on December 28, 1887; second to Miss Margaret McDermott of New York City. Two daughters survive, one of each marriage; Dr. Justina Hill of Johns Hopkins University Medical School, and Mrs. Jean Hill Guttormsen of Los Angeles, California.

What shall be said of his lasting contribution to the field of Science? No more can this be summarized briefly, than the foregoing can be held a complete summation of his long and active career. Only generalizations are possible in this short review.

He subdivided, classified on both paleontological and stratigraphic criteria, and mapped areally, by reconnaissance methods, the Cretaceous strata of the Southwest. The work was so well done that subsequent efforts have resulted chiefly in mere refinements and further subdivision. His paleontological nomenclature has been supplanted by geographic names, but few, if any, fundamental changes have been necessary. He established the identity and geologic age of the Comanche series, and gave to it the name which has become securely established in geological literature the world over. This task alone is a most creditable lifetime accomplishment for one individual. It is all the more creditable in view of prior misconceptions and the very limited antecedent knowledge of the Cretaceous geology of the region. His Black and Grand Prairie report was in great demand and copies sold up to $50 each during the period of intensive oil development in East and Central Texas—surely a superb testimonial to work well done some 25 years earlier. In connection with his Cretaceous study, it should be noted that he detected the true character of the Balcones Fault zone and gave it its name.

He contributed greatly to the knowledge of underground waters throughout the Southwest at a time when the information was of great value in the economic development of this practically virgin area. His Physiographic Atlas of Texas, published in 1901, remains to-day the best interpretation of the geographic features of the region.

His Antillean geology was so well grounded that Charles Schuchert ranked him the "Father of Antillean and Isthmian Geology," and stated further that his work "forms the broad foundation on which all subsequent geologic work on the Antillean region must be built. No one has a better grasp of the genesis and orogeny of this very significant area than Hill."[1]

Through his popular writing he did more perhaps than any other individual to interpret and popularize not only geology but the various related sciences for the laymen of the Southwest.

And what shall we say of him as a man? He was at heart a scientist. He worked unceasingly on scientific problems with scarcely a thought of their economic implications—often at very considerable expense to himself. He craved little of this world's goods, and was profligate in the use of that which came his way. One might wish that he had been less combative toward those who differed from his conclusions—that he had been more tolerant of dissenting opinions, honestly held. But one must remember that he was brought up in a harsh environment where concessions were seldom granted unless stoutly defended. He created for himself a unique place in the annals of science, and a widely acclaimed recognition throughout the Southwest and the nation. His

[1] Charles Schuchert, *Historical Geology of the Antillean-Caribbean Region*, p. 2. New York (1935).

name and his memory will live long among the people he most loved and for whom he devoted the efforts of his last years, the people of Texas.

Note.—Following a brief ceremony on October 26, 1941, during which the foregoing memorial was read, Dr. Hill's ashes were scattered over Round Mountain, Comanche County, in the presence of numerous friends and geological associates. There he was inspired to follow a geological career, and it was his oft repeated wish that his ashes should find their final resting place in this spot, for which he had formed a strong sentimental attachment.

W. E. WRATHER

DALLAS, TEXAS
October, 1941

BAKER HOSKINS, JR.

(1900–1941)

Baker Hoskins, Jr., was born on May 27, 1900, in Norfolk, Virginia, and died on June 22, 1941, in Lake Charles, Louisiana, following a surgical operation. Interment took place at Waco, Texas.

He is survived by his widow, Bonnie Parrish Hoskins, formerly of Lake Charles, Louisiana, and now of Nacogdoches, Texas; his parents, Mr. and Mrs. Baker Hoskins, Sr., of Wellington, Texas; one brother, Fred Hoskins, of Waco, Texas; and a sister, Mrs. James Bush, of Helena, Arkansas.

Baker attended the University of Texas from 1918 to 1921, majoring in geology, and during the summer months was associated with his father in the cotton business at Waco, Texas. He belonged to the Episcopal Church. He was a member of Sigma Chi and Sigma Gamma Epsilon fraternities and joined the American Association of Petroleum Geologists in 1926. His sponsors for association membership were Hal. P. Bybee, Joseph M. Dawson, and Thomas B. Romine. He became an active member in 1929.

Shortly after completing his studies at the University of Texas, Baker accepted a position in the geological department of the Shell Petroleum Corporation. He resigned from this position in 1925 to join the staff of the United North and South Development Company, Luling, Texas. From 1926 to 1928, Baker was associated with W. C. McBride, Inc., St. Louis, Missouri, during which time he was engaged for the most part in geological work in the state of Texas. In 1928, he re-entered the employment of the Shell Petroleum Corporation and remained with this concern until the time of his death.

Baker Hoskins, Jr., was a charter member of the South Louisiana Geological Society which was organized in 1936. In January, 1937, he was elected treasurer of this society which position he held at the time of his death, having been elected to this office five consecutive times. Baker took a great deal of pleasure in keeping the coffers of the South Louisiana Geological Society well supplied with funds. In fact, he rather enjoyed bantering with an occasional member whose dues happened to be in arrears. At repartee, Baker was at his best.

One of Baker's outstanding characteristics was the unselfish manner in which he assisted his fellow man in his particular problem. He seemed to con-

sider it his duty, as well as a privilege to help a newcomer to familiarize himself with a given territory. There are many of the oil fraternity, geologists, scouts, and others who well remember numerous instances in which Baker befriended them. His pleasant personality, genial good humor, and willingness to serve made him liked by all who came in contact with him. His conscientious exactness and alertness in the performance of every duty made him a very valuable employee. A true sportsman, he enthusiastically enjoyed hunting and

BAKER HOSKINS, JR.

fishing. Perhaps, it is through these favorite recreational hobbies that he attained his generous and optimistic outlook on life which was an inspiration to all who knew him.

Baker's hospitality and genuine interest in his guests made him at all times a most gracious host. He was rightfully proud of the attractive home which he built in Lake Charles, which he lived to enjoy with his charming wife for several years prior to his death.

His host of friends and admirers deeply regret the untimely passing of a great personality who held their respect and affection.

H. V. TYGRETT

LAKE CHARLES, LOUISIANA
October 21, 1941

ARTHUR ALBERT WEDEL
(1898–1941)

Arthur Albert Wedel was apparently recovering from a very serious operation in the Good Samaritan Hospital, Los Angeles, California, when he was taken by death on May 7, 1941. He had enjoyed robust health until a short time before his untimely death.

Arthur Wedel was born at Moundridge, Kansas, February 16, 1898, the

ARTHUR ALBERT WEDEL

son of John H. Wedel and Veronika Zerger Wedel. He attended Moundridge grade and high schools, and studied for a time at Bethel College in near-by Newton. After attending Oberlin College and De Pauw University, he did graduate work at Cornell University where he earned the degree of Doctor of Philosophy in geology. At various times his studies were interrupted by periods of teaching. One year, he taught in a country district school near Moundridge. Later, he taught in the Hill City, Kansas, High School for one year followed by two years in the Hardtner, Kansas, High School and three years in the Leoti, Kansas, High School.

After his graduation from Cornell in June, 1930, Wedel joined the geologic staff of the Pure Oil Company, and he was associated with the company at the time of his sudden death. Being very versatile, he showed great skill not

only in the mapping of surface structure but in paleontology and subsurface geology. He was a profound student of geology and although he found time to publish but one paper,[1] he influenced geologic thought in most of the areas in which he worked. Undoubtedly he would have made important contributions to geologic literature had he lived.

Arthur and his wife, Maybelle Alice Beeby Wedel, whom he married, May 28, 1928, made a host of friends in the many states in which he worked. He was of retiring nature, loyal, sincere, inspiring, and possessed of a keen sense of humor. Being a student of philosophy, world affairs, and human nature as well as of geology, his conversation was most interesting, and his friends will long remember many lively discussions on various subjects. He was widely respected as a geologist and teacher and even more widely esteemed as a man of sterling qualities.

While at Cornell, Wedel was elected to Sigma Xi. He was a member of the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists, the American Association for the Advancement of Science, the Mineralogical Society of America, the Paleontological Research Institution of Ithaca, New York, the Indiana Academy of Science, and the Mississippi Geological Society.

Wedel is survived by his widow, six sisters, and five brothers.

IRA H. CRAM

CHICAGO, ILLINOIS
November, 1941

[1] Arthur Albert Wedel, "Geologic Structure of the Devonian Strata of South-Central New York," *New York State Mus. Bull. 294* (November, 1932).

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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

J. FRENCH ROBINSON, president of the East Ohio Gas Company, Cleveland, Ohio, was elected chairman of the natural gas section at the recent meeting of the American Gas Association at Atlantic City, New Jersey.

WILLIAM A. BAKER, JR., geologist, is located at 1515 Esperson Building, Houston, Texas, for consulting work in examinations, surveys, and appraisals.

WILLIAM LYNN KREIDLER is with the Tide Water Associated Oil Company, 737 Esperson Building, Houston, Texas.

LEONARD W. HENRY, recently with the Standard Oil Company of California at San Francisco, is in the employ of the Richmond Petroleum Company of Colombia, Apartado Nacional 2760, Bogota, Colombia.

HUGH ALLEN BERNARD may be addressed at Box 474, Southwestern Louisiana Institute, Lafayette, Louisiana.

HARRY WILLIAMSON, of the Arkansas Fuel Oil Company, has moved from Shreveport to 1452 Canal Building, New Orleans, Louisiana.

ARTHUR ALBERT WEDEL, geologist with the Pure Oil Company, died at Los Angeles, California, May 7, following an operation.

W. C. IMBT, of the Stanolind Oil and Gas Company, Wichita, Kansas, presented a paper on "The Zenith Pool, Stafford County, Kansas, an Example of Stratigraphic Trap Accumulation," before the Tulsa Geological Society, November 3.

CHARLES A. DURHAM, formerly with the Humble Oil and Refining Company at Houston, may be addressed c/o International Petroleum Company, Ltd., Guayaquil, Ecuador, S. A.

G. A. WARING of the U. S. Geological Survey at Washington, may be addressed at BOX 1144, Tucson, Arizona, through the winter months.

ALBERT WYNN, of the Kerlyn Oil Company, has been transferred from Wichita, Kansas, to 202 Davis Street, Gainesville, Texas.

H. M. GOODMAN is now a lieutenant in Company B, 35th Bn., E.R.T.C., at Fort Leonard Wood, Missouri.

C. MAYNARD BOOS was the speaker at a meeting of the Rocky Mountain Association of Petroleum Geologists, at Denver, November 3. His subject was "The Search for Refractory Minerals of Defense Importance in Colorado."

R. B. NEWCOMBE is now in charge of Petroleum Development Section, Office of Petroleum Coördinator for National Defense, Production Division. This office address is District 2 at 120 South La Salle Street, Chicago, Illinois. His home address is 1806 Pleasant Avenue, Highland Park, Illinois.

WARREN L. CALVERT has moved from Vincennes, Indiana, to 106 N.W. Second Street, Fairfield, Illinois.

J. E. JOUJON-ROCHE, formerly of Pacific Grove, California, may be addressed at 512 Fontaine Street, Alexandria, Virginia.

JOHN MARSHALL, who has been with The Texas Company in Wichita, Kansas, has been transferred to Ardmore, Oklahoma. His box number is 539.

L. B. HERRING, consulting geologist, has changed his address from the Nixon Building to 701–2 Driscoll Building, Corpus Christi, Texas. E. A. TAEGEL has been added as a permanent member to the firm.

ROBERT P. MILLER may be addressed in care of the Richmond Petrolum Company of Colombia, Apartado Nacional 2760, Bogota, Colombia, S. A.

L. H. FREEDMAN has resigned his position with Snowden and McSweeney Company, with whom he has been associated for more than twenty years, and is now available for consultation at 116 Hazelwood Drive, Fort Worth, Texas.

New officers of the Indiana-Kentucky Geological Society for 1941–1942 are: president, EDMUND T. BENSON; vice-president, R. R. MUNOZ; and secretary-treasurer, EDWARD J. COMBS, Sun Oil Company, Old National Bank Building, Evansville, Indiana. J. A. BROWN and D. G. SUTTON were named executive officers.

WARREN B. WEEKS of Shreveport, Louisiana, spoke on "The Geology of the Schuler Field, Union County, Arkansas" at a meeting of the Shreveport Geological Society on November 7.

JULIUS WM. SCHMOTZER, Arkansas Fuel Oil Company, has been transferred from the San Antonio district to the Houston office as district geologist. He may be addressed at Box 283, Houston, Texas.

VAN D. ROBINSON has been named district geologist in the North Louisiana and Arkansas area for Atlantic Refining Company, succeeding SAM M. ARONSON, who resigned. His office is located in the City Bank Building, Shreveport, Louisiana.

DOUGLAS D. HOWARD has resigned his position with Arkansas Fuel Oil Company, Shreveport, Louisiana, to accept a position with Penrod Drilling Company, Dallas, Texas.

GEOFFREY BARROW, formerly with the Papuan Apinaipi Petroleum Company, Ltd., Papua, may be addressed in care of the Tropical Oil Company, El Centro, Colombia, South America.

GEORGE N. MAY, Union Sulphur Company, Sulphur, Louisiana, is treasurer of the South Louisiana Geological Society, completing the term of BAKER HOSKINS, JR., recently deceased.

H. N. FISK, associate professor of geology at Louisiana State University, Baton Rouge, gave a paper on "The Midway-Wilcox Deltaic Mass," before the South Louisiana Geological Society, Lake Charles, October 21.

FRANK V. STEVENSON, recently at Walker Museum, University of Chicago, is with the Arkansas Geological Survey, Little Rock, Arkansas.

M. HALL TAYLOR, who has held a Cutting Traveling Fellowship from Columbia University during the past year, has completed a research project on middle Paleozoic rocks of the Kansas subsurface section, and is now a 1st Lieutenant in the Coast Artillery at Camp Wallace, Texas.

The West Texas Geological Society, meeting recently at Midland, Texas, listened to L. E. NUGENT, of The Texas Company, on "Theories of Geomorphic Development," and RONALD K. DEFORD, of the Argo Corporation, on "Highlights of the New Mexico School of Mines Field Trip."

The Shawnee Geological Society, Shawnee, Oklahoma, heard STANLEY B. WHITE, of the Ohio Oil Company, Tulsa, speak on "The Davenport Pool of Lincoln County," November 20.

M. T. HALBOUTY, consulting geologist and engineer, read a paper on "The Geology and Economic Significance of Flank Production on the Jennings Dome, Acadia Parish, Louisiana," before the Houston Geological Society, November 6.

JOHN A. LIMING, who returned from Venezuela in 1940 and served a year as first lieutenant in the army, is now in the geophysical department of the Stanolind Oil and Gas Company, Tulsa, Oklahoma.

Lieutenant EMIL MONSOUR, of the Sun Oil Company, may be addressed at the Air Corps Replacement Center, Maxwell Field, Alabama.

G. R. SPARENBERG is with the Lane-Wells Company, 2002 Wayside Drive, Houston, Texas.

Geologists in New Orleans and adjacent areas of southeastern Louisiana organized the New Orleans Geological Society, October 6, 1941. The organization of this Society was made possible by the fact that within the year The Texas Company, the Humble Oil and Refining Company, The California Company, and the Arkansas Fuel Oil Company have moved offices and a considerable number of geologists to New Orleans, which increased the ranks of geologists already located in the city and adjacent areas. The following officers were elected for the current year: president, GEORGE W. SCHNEIDER, The Texas Company; vice-president, R. A. STEINMAYER, Tulane University; secretary-treasurer, HARLUF C. PETERSEN, Freeport Sulphur Company, all of New Orleans. The membership list includes fifty-five. Of this number, twenty-one are members and five are associate members of the A.A.P.G. Regular meetings will be held on the first Monday in the month. The speaker at the first regular meeting on November 3, 1941, was URBAN B. HUGHES, consulting geologist of Jackson, Mississippi, who talked on "Outline of Mississippi Geology."

New officers of the North Texas Geological Society of Wichita Falls, Texas, are: president, ROBERT ROTH, Humble Oil & Refining Company; vice-president, F. E. MELOTT, Deep Rock Oil Company; and secretary-treasurer, DOLPHE E. SIMIC, Cities Service Oil Company.

Lieutenant Colonel BYRON RIFE has been transferred from Baytown Ordnance Works, Baytown, Texas (Toluol), to the new Ammonia Plant at Missouri Ordnance Works, Louisiana, Missouri, where he will be in command.

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INDEX OF VOLUME 25 (1941)

Abernathy, G. E. Migration of Oil from Arbuckle Limestone into Chattanooga Shale in Chetopa Oil Pool, Labette County, Kansas 1934
Abstracts of Papers, Annual Association Meeting, Houston, Texas, April 2–4, 1941. The Association Round Table. 928
——— at Pacific Section Eighteenth Annual Meeting, Los Angeles, October 16–17, 1941. The Association Round Table 2093
———, of General Interest. The Association Round Table 936
———, on California Area. The Association Round Table 946
———, on Central and Eastern States Area. The Association Round Table . 942
———, on Gulf Coast Area. The Association Round Table 928
———, on North Mid-Continent Region. The Association Round Table . . 945
———, on Rocky Mountain Section. The Association Round Table . . . 938
———, on South Mid-Continent Region. The Association Round Table . . 940
———, on South Texas Area. The Association Round Table 931
———, on West Texas Area. The Association Round Table 933
———, Pacific Section Eighteenth Annual Meeting, Los Angeles, October 16–17, 1941. The Association Round Table 2093
Abyssal Deposits of East Indian Archipelago, Age of. Geological Note by Carl C. Branson. 320
Accumulation, Oil, and Marine Sedimentation on Gulf Coast. I. Progressive Marine Overlap. By Doris S. Malkin and Dorothy A. Jung 2010
Accumulation and Migration of Petroleum, Report of Committee on. By F. M. Van Tuyl and Ben H. Parker. The Association Round Table 973
Acidizing Oil Reservoirs Composed of Sands, Laboratory and Field Observations of Effect of. By P. E. Fitzgerald, F. R. James, and Ray L. Austin . . 850
———. Abstract 937
Adkins, W. S. Review of Lower Cretaceous and Jurassic Formations of Southern Arkansas, by Ralph W. Imlay 329
Age of Abyssal Deposits of East Indian Archipelago. Geological Note by Carl C. Branson. 320
———, of Shale in Amoura-Uscari Area, Costa Rica. By William W. Porter II and Paul P. Goudkoff. Abstract 947
Ahlfeld, Friedrich, and Reyes, Jorge Muñoz. Die Bodenschätze Boliviens (The Mineral Resources of Bolivia). Review by John L. Rich 333
Alaska, Possible Future Oil Provinces in. By Philip S. Smith. 1440
Allen, H. B., Eaton, J. E., and Grant, U. S. Miocene of Caliente Range and Environs, California 193
American Association for the Advancement of Science, Dallas, December 29–31. Announcement. At Home and Abroad 1966
American Association of Petroleum Geologists. Conferences at Twenty-Sixth Annual Meeting. The Association Round Table 976
———. Constitution and By-Laws. The Association Round Table 982
———. Executive Committee Meetings. The Association Round Table. . . 954
———. Finances. The Association Round Table 953, 957
———. Financial Statement, Division of Paleontology and Mineralogy, for 1940. The Association Round Table. 453
———. Financial Statement for 1940. The Association Round Table . . . 448
———. Membership List, March 6, 1941. The Association Round Table . . 457
———. Membership List, Supplementary, September 1, 1941. The Association Round Table 1821
———. Minutes, Twenty-Sixth Annual Business Meeting, Rice Hotel, April 2–4, 1941. By Edgar W. Owen. The Association Round Table 951
———, Pacific Section of. Possible Future Oil Provinces in Pacific Coast States 1457
———. Past and Present Officers of the Association. The Association Round Table 545
———. Presidential Addresses at Twenty-Sixth Annual Meeting. The Association Round Table 935

———. Round Table Discussions at Twenty-Sixth Annual Meeting. The Association Round Table 976
———. Twenty-Sixth Annual Meeting, Rice Hotel, Houston, Texas, April 2–4, 1941. The Association Round Table. 918
American Institute of Mining and Metallurgical Engineers. Geophysics, 1940. Review by John L. Ferguson. 760
———, Petroleum Division. Petroleum Development and Technology, 1941. Review by G. S. Dillé. 1950
Amoura-Uscari Area, Costa Rica, Age of Shale in. By William W. Porter II and Paul P. Goudkoff. Abstract 947
Analysis of Midway Fauna of Western Gulf Province. By Julia Gardner. . . . 644
Announcement. By A. I. Levorsen. Research Notes 177
Annual Meeting, Twenty-Sixth, The American Association of Petroleum Geologists, Rice Hotel, Houston, Texas, April 2–4, 1941. The Association Round Table 918, 2220
Annual Reviews of Petroleum Technology. By the Institute of Petroleum. Review by J. E. Brantly 327
Antrim-Ellsworth-Coldwater Shale Formations in Michigan. By Eleanor Tarbell 724
Appalachian, Post, Faulting in Western Kentucky. By Roger Rhoades and Alvin J. Mistler 2046
Appalachian Area, Developments in, during 1940. By Appalachian Geological Society 1135
Appalachian Geological Society. Developments in Appalachian Area in 1940 . 1135
———. Possible Future Oil Provinces in Eastern United States 1563
Appalachian Geosyncline, Central Basin of. By Robert C. Lafferty 781
Appalachian Province, Geochemistry of Natural Gas in. By Paul H. Price and A. J. W. Headlee. Abstract 942
Appalachian Structure, Some Problems of. By R. E. Sherrill 416
Appanoose County, Iowa, Traverse of Upper Des Moines and Lower Missouri Series from Jackson County, Missouri, to. By L. M. Cline 23
Applications of Radioactivity Logging. By William L. Russell. Abstract . . 938
Applied Sedimentology. Geological Note by Henry Carter Rea 899
Arbuckle of Central Kansas Uplift, Stream Channels Applied to. By J. A. Mull. Abstract 946
Arbuckle and Wichita Mountains of Oklahoma, Simpson Group of. By Charles E. Decker 650
Arbuckle Limestone, Migration of Oil from, into Chattanooga Shale in Chetopa Oil Pool, Labette County, Kansas. Geological Note by G. E. Abernathy. 1934
Archer County, Texas, Coleman Pool Discovery. Geological Note by Ward C. Bean. 428
Arkansas, Southern, Lower Cretaceous and Jurassic Formations of. By Ralph W. Imlay. Review by W. S. Adkins 329
———, Southern, and Northern Louisiana, Developments in, during 1940. By Joseph Purzer and Warren B. Weeks 1024
———. Abstract 943
Artinskian Series in Russia, Classification of. By G. Marshall Kay 1396
Association Committees 182, 340, 446, 776, 914, 1190, 1428, 1608, 1826, 1958, 2088, 2218
Association Executive Committee. The Association Round Table 927
Association Finances. The Association Round Table 953, 957
Association Membership Data. The Association Round Table 955
Association Membership List, March 6, 1941. The Association Round Table . 457
———, Supplementary, September 1, 1941. The Association Round Table. . 1821
Association Round Table, The . . . . . 178, 338, 444, 772, 911, ... 1186, 1425, 1605, 1617, 1820, 1954, 1966, 2087, 2216
At Home and Abroad . 185, 349, 551, 778, 991, 1192, 1430, 1613, 1833, 1964, 2102, 2232
Atwill, E. R., and Galliher, E. W. Progress of Stratigraphic Studies in California. Abstract 946
Austin, Ray L., Fitzgerald, P. E., and James, F. R. Laboratory and Field Observations of Effect of Acidizing Oil Reservoirs Composed of Sands. . . . 850
———. Abstract 937
Australia, Tertiary Geology of. By F. A. Singleton. Review by Burton Wallace Collins 1813

———, Western, Upper Paleozoic of: Correlation and Paleogeography. By Curt Teichert 371, 1809
Avoyelles Parish, Louisiana, Geology of Eola Oil Field. By Fred W. Bates. 1363, 1597

Bakersfield Area, California, Pre-Miocene Stratigraphy of. By Alex Clark. Abstract 947
Bald Mountain-Freezeout Mountain Area, Carbon County, Wyoming, Geology of. By Milan D. Maravich 883
Ball, Max W., Weaver, T. J., and Ball, Douglas S. Shoestring Sand Gas Fields of Michigan. Abstract 942
Barataria Field, Jefferson Parish. Louisiana. Geological Note by Al Ferrando and H. T. Richardson 322
Barcklow, J. C. Radioactivity Well Logs, Their Use and Application in Fields of Petroleum Geology, Economic Geology, and Petroleum Engineering. Abstract 938
Barry, John O. Correlation of Wilcox Faunal Units of Louisiana. Abstract . . 941
Barry, John O., and LeBlanc, Rufus J. Fossiliferous Localities of Midway Group in Louisiana. Geological Note 734
Bartelso Oil Field, Clinton County, Illinois, Geology of. By James L. Carlton. Abstract 944
Bartle, Glenn G. Effective Porosity of Gas Fields in Jackson County, Missouri. Abstract 947
———. Geological Note 1405
Barton, Donald C. Correlation of Crude Oils with Special Reference to Crude Oil of Gulf Coast 561
Bartram, John G. Report of Committee on Geologic Names and Correlations. The Association Round Table 977
———. Sub-Committee on Tertiary. The Association Round Table . . . 2098
Basal Vicksburg Sand of Texas Gulf Coast. By A. N. Wilson. Abstract . . . 931
Basin, Central, of Appalachian Geosyncline. By Robert C. Lafferty. . . . 781
Bass, N. Wood. Significance of Initial Daily Production of Wells in Burbank and South Burbank Oil Fields, Oklahoma. Geological Note 1175
Bates, Fred W. Geology of Eola Oil Field, Avoyelles Parish, Louisiana . 1363, 1597
Bates, Robert L. Lateral Gradation in Seven Rivers Formation, Rocky Arroyo, Eddy County, New Mexico. Abstract 935
———. Review of Internal Constitution of the Earth, edited by G. Gutenberg . 172
Bean, Ward C. Coleman Pool Discovery, Archer County, Texas. Geological Note. 428
Beckwith, R. H. Trace-Slip Faults 2181
Beers, Lowell C. Radioactivity Well Logging through Casing. Abstract . . . 2098
Beers, Roland F. Review of Strength and Structure of the Earth, by Reginald Aldworth Daly. 1181
Beljaev, G., Rauser-Černoussova, D., and Reitlinger, E. On Carboniferous Foraminifera of the Samara Bend. Review by Siemon Wm. Muller and Hubert G. Schenck 1943
Bell, Alfred H. Developments in Eastern Interior Basin in 1940 1114
———. Oil and Gas Development in Eastern Interior Basin in 1940. Abstract 942
Benton and Niobrara in Foothills of Northern Colorado, Microfaunas of. By W. C. Toepelman. Abstract 940
Bertagnolli, A. J., Jr. Geology of Southern Part of La Barge Region, Lincoln County, Wyoming. 1729
Blau, L. W. Review of Exploration Geophysics, by J. J. Jakosky 170
Bodenschätze Boliviens, Die. By Friedrich Ahlfeld and Jorge Muñoz Reyes. Review by John L. Rich 333
Bolivia, The Mineral Resources of. By Friedrich Ahlfeld and Jorge Muñoz Reyes. Review by John L. Rich 333
Borden, Joseph L. Review of Oil and Gas Field Development in United States, 1940, by National Oil Scouts and Landmen's Association 1942
Born, Kendall E. Oil and Gas Possibilities in Northern Cumberland Plateau. Abstract 944
Born, W. T. The Future of Geophysics 1256
Bowsher, Arthur L., and Laudon, L. R. Mississippian Formations of Sacramento Mountains, New Mexico 2107

———. Abstract 935
Brace, O. L. Review of Developments in 1940, Gulf Coast of Upper Texas and Louisiana 1004
———. Abstract 928
Bradford Oil Field, Pennsylvania, Graywackes and the Petrology of. Discussion by Paul D. Krynine 2071
Bradford Sand, Third, Petroleum and Genesis of. By Paul D. Krynine. Review by Parke A. Dickey 1413
Branson, Carl C. Age of Abyssal Deposits of East Indian Archipelago. Geological Note 320
Branson, E. B., and Branson, C. C. Geology of Wind River Mountains, Wyoming 120
Brantford Area, Ontario, Natural Gas in. By J. F. Caley. Review by Charles S. Evans 1950
Brantly, J. E. Review of Annual Reviews of Petroleum Technology, by the Institute of Petroleum 327
Brazos River and Rio Grande, Late Cenozoic Deposits of Texas Coastal Plain between. By A. W. Weeks. Abstract 932
Breckenridge Field, Stephens County, Texas, Relation of Initial Production to Ultimate Production of Wells Completed in Smithwick (Gray) Limestone. Geological Note by David Donoghue 1589
Brehm, Clarence E. Pickens Pool, Yazoo County, Mississippi. Abstract . . 931
Britt, Harry Max, Jr. West Texas Geological Society Student Merit Award. The Association Round Table 1188
Buchanan, George S. Remarks at Opening of Twenty-Sixth Annual Meeting . 1201
Bulletin Papers, Source of. The Association Round Table 962
Burbank and South Burbank Oil Fields, Oklahoma, Significance of Initial Daily Production of Wells in. Geological Note by N. Wood Bass 1175
Business Committee, Report (Minutes) of. By Edgar W. Owen. The Association Round Table 964
Business Meeting, Twenty-Sixth Annual, Rice Hotel, Houston, Texas, April 2–4, 1941, Minutes. By Edgar W. Owen. The Association Round Table . . . 951

Caley, J. F. Natural Gas in Brantford Area, Ontario. Review by Charles S. Evans 1950
Caliente Range and Environs, California, Miocene of. By J. E. Eaton, U. S. Grant, and H. B. Allen 193
California, An Introduction to the Cretaceous of. By Olaf P. Jenkins. Abstract. 2094
———, Cretaceous—East Side Sacramento Valley. By W. P. Popenoe. Abstract 2095
———, Cretaceous of Santa Lucia Range. By N. L. Taliaferro. Abstract . . 2095
———, Cretaceous Vertebrate Record of. By Charles Stock. Abstract . . . 2094
———, Cretaceous—West Side Sacramento Valley North of Willows. By Philip W. Reinhart. Abstract 2095
———, Crocker Flat Infolded Landslide and Coarse Clastics in Temblor Range. By Russell R. Simonson and Max L. Kreuger. Abstract 2097
———, Del Valle Oil Field, Los Angeles County. By R. W. Sherman. Abstract. 947
———, Discussion of Part of Upper Cretaceous Along West Border of San Joaquin Valley. By A. S. Huey and J. W. Daly. Abstract 2096
———, Exploration Work in, during 1940. By Eugene H. Vallat. Abstract . 946
———, Geological Notes on Oak Canyon Oil Field. By Wayne Loel, R. W. Clark, and Paul P. Goudkoff. Abstract 2096
———, Geology of Del Valle Area. By L. A. Tarbet. Abstract 2096
———, Miocene of Caliente Range and Environs. By J. E. Eaton, U. S. Grant, and H. B. Allen 193
———, Northwest Extension of Inglewood Field. By Robin Willis. Abstract. . 2097
———, Pre-Miocene Stratigraphy of Bakersfield Area. By Alex Clark. Abstract 947
———, Progress of Stratigraphic Studies in. By E. W. Galliher and E. R. Atwill. Abstract 946
———, Seismic Velocity Variations in San Joaquin Valley. By Walter S. Olson 1343
———, Southern, Miocene Fishes in Well Cores from Torrance. Geological Note by Lore David 319
———, Stevens Sand, Southern San Joaquin Valley. By Rollin Eckis. Abstract 946

———, Thrust Faulting and Coarse Clastics in Templor Range. By F. S. Hudson and G. H. White 1327
———, Upper Cretaceous Stratigraphy of West Side of Sacramento Valley South of Willows, Glenn County. By James M. Kirby. Abstract . . . 2095
California Area, Abstracts of Papers on. The Association Round Table . . 946
California Coast, Submarine Topography off the: Canyons and Tectonic Interpretation. By Francis P. Shepard and K. O. Emery. Review by John L. Ferguson 1940
California Exploration and Development in 1940. By Eugene H. Vallat . . 1159
California Oil Fields—before Discovery and after Development. By James C. Kimble. Abstract 2096
Campbell, Marius Robinson. Memorial by G. B. Richardson 546
Campbell, Robert B. Review of Proceedings of the Florida Academy of Sciences for 1939 168
Canada, Eastern, Possible Future Oil Provinces of. By Geological Survey of Canada, Quebec Bureau of Mines, and Newfoundland Geological Survey . 1539, 2194
———, Western, Possible Future Oil Provinces in. By Alberta Society of Petroleum Geologists 1447
Canada and the United States, Possible Future Oil Provinces of. Foreword. By A. I. Levorsen 1433
Cantrell, Ralph B., and Casey, S. Russel. Davis Sand Lens, Hardin Field, Liberty County, Texas. Abstract 930
Canyons and Tectonic Interpretation: Submarine Topography off the California Coast. By Francis P. Shepard and K. O. Emery. Review by John L. Ferguson 1940
Cap Rocks, Salt-Dome, Gold, Silver, and Other Elements in. Geological Note by Marcus A. Hanna and Albert G. Wolf 750
Carbon County, Wyoming, Geology of Freezeout Mountain-Bald Mountain Area. By Milan D. Maravich 883
Carboniferous Foraminifera of the Samara Bend. By D. Rauser-Černoussova, G. Beljaev, and E. Reitlinger. Review by Siemon Wm. Muller and Hubert G. Schenck 1943
Carlton, James L. Geology of Bartelso Oil Field, Clinton County, Illinois. Abstract 944
Casebeer, Charles Theodore. Memorial by E. A. Paschal 1831
Casey, S. Russel, and Cantrell, Ralph B. Davis Sand Lens, Hardin Field, Liberty County, Texas. Abstract 930
Casing, Radioactivity Well Logging through. By Lowell C. Beers. Abstract . 2098
Caster, Kenneth E. The Titusvilliidae; Paleozoic and Recent Branching Hexactinellida. Review by W. A. Ver Wiebe 2082
Cementing Materials in Sandstones and Their Influence on Migration of Oil. By W. A. Waldschmidt 1839
Cenozoic Deposits, Late, of Texas Coastal Plain between Brazos River and Rio Grande. By A. W. Weeks. Abstract 932
Centennial, Wyoming, Permian Correlation Meeting, September 2, 1940. Geological Note by Ronald K. DeFord 429
Central and Eastern States Area, Abstracts of Papers on. The Association Round Table 942
Central Basin of Appalachian Geosyncline. By Robert C. Lafferty 781
Central Kansas Uplift, Stream Channels Applied to Arbuckle of. By J. A. Mull. Abstract 946
Central Texas, Ellenburger Structure Map of. By A. I. Levorsen. Research Notes 1600
Chambers County, Texas, South Cotton Lake Field. By Joseph M. Wilson . 1898
Chattanooga Shale in Chetopa Oil Pool, Labette County, Kansas, Migration of Oil from Arbuckle Limestone into. Geological Note by G. E. Abernathy . 1934
Chester of Illinois Basin, Cross Section of. By P. L. Dana and E. H. Scobey . . 871
Chetopa Oil Pool, Labette County, Kansas, Migration of Oil from Arbuckle Limestone into Chattanooga Shale in. Geological Note by G. E. Abernathy 1934
Clark, Alex. Pre-Miocene Stratigraphy of Bakersfield Area, California. Abstract 947
Clark, R. W., Loel, Wayne, and Goudkoff, Paul P. Geological Notes on Oak Canyon Oil Field. Abstract 2096
Classification of the Artinskian Series in Russia. By G. Marshall Kay . . . 1396

Clastics, Coarse, and Crocker Flat Infolded Landslide in Temblor Range, California. By Russell R. Simonson and Max L. Krueger. Abstract . . . 2097
———, Coarse, and Thrust Faulting in Temblor Range, California. By F. S. Hudson and G. H. White . . . 1327
Cline, L. M. Traverse of Upper Des Moines and Lower Missouri Series from Jackson County, Missouri, to Appanoose County, Iowa . . . 23
Clodine Field, Fort Bend County, Texas. Geological Note by Jack O. Colle . . 2057
Coarse Clastics and Thrust Faulting in Temblor Range, California. By F. S. Hudson and G. H. White . . . 1327
Coastal Plain, Texas, Late Cenozoic Deposits between Brazos River and Rio Grande. By A. W. Weeks. Abstract . . . 932
Coldwater-Antrim-Ellsworth Shale Formations in Michigan. By Eleanor Tarbell 724
Cole, Taylor. Midland, Texas, Insoluble Residue Study Group. Geological Note 318
———. Subsurface Study of Ellenburger Formation in West Texas. Abstract . 934
Cole, Taylor, Dickey, Robert I., and Kraus, Edgar. Developments in West Texas and Southeastern New Mexico during 1940 . . . 1044
———. Abstract . . . 933
Coleman Pool Discovery, Archer County, Texas. Geological Note by Ward C. Bean 428
Colle, Jack O. Clodine Field, Fort Bend County, Texas. Geological Note . . 2057
College Curricula, Report of Special Committee on. The Association Round Table . . . 969
Collier, John J., Jr., Houston Geological Society Student Award. The Association Round Table . . . 1607
Collins, Burton Wallace. Review of Divisions of Upper Cretaceous and Tertiary in New Zealand, by H. J. Finlay and J. Marwick . . . 1813
———. Review of Tertiary Geology of Australia, by F. A. Singleton . . . 1813
Colombia, Pre-Cretaceous Sediments in Cordillera Oriental of. By Parke A. Dickey . . . 1789
Color of Sedimentary Rocks, Relation of Organic Matter to. By H. Whitman Patnode . . . 1921
Colorado, Northern, Microfaunas of Niobrara and Benton in Foothills of. By W. C. Toepelman. Abstract . . . 940
———, Southwestern, Correlation of Cross' La Plata Sandstone. By Marcus I. Goldman and Arthur C. Spencer . . . 1745
Colorado and Rocky Mountain Region, Guidebooks on . . . 2092
Comparative Study of Origin and Distribution of Gulf Coast Tertiary Sediments. By Carl B. Richardson. Abstract . . . 929
Conferences at Twenty-Sixth Annual Meeting, American Association of Petroleum Geologists. The Association Round Table . . . 976
Constitution of the Earth, Internal. Edited by G. Gutenberg. Review by Robert L. Bates . . . 172
Constitution and By-Laws, American Association of Petroleum Geologists. The Association Round Table . . . 982
Contour Maps, Resulting Shadowgraphic, Experiments with Lights, Shadows, and Contours, and. By Robert F. Imbt . . . 2161
Cordillera Oriental of Colombia, Pre-Cretaceous Sediments of. By Parke A. Dickey . . . 1789
Cordry, C. D., and Upson, M. E. Silurian Production, Shipley Field, Ward County, Texas. Geological Note . . . 425
Correlation of Cross' La Plata Sandstone, Southwestern Colorado. By Marcus I. Goldman and Arthur C. Spencer . . . 1745
——— of Crude Oils with Special Reference to Crude Oil of Gulf Coast. By Donald C. Barton . . . 561
——— of Subsurface Sections with Outcrops of Ellenburger Formation of Texas. By Leo Hendricks. Abstract . . . 943
——— of Upper Midway Fauna of Louisiana. By R. J. Le Blanc. Abstract . 941
Correlation and Paleogeography: Upper Paleozoic of Western Australia. By Curt Teichert . . . 371, 1809
Correlation Chart, Tentative, of Gulf Coast. Geological Note by Chalmer J. Roy and Albert R. Glockzin . . . 742
Correlations of Wilcox Faunal Units of Louisiana. By J. O. Barry. Abstract . . 941
———, Paleozoic, from Southern Rocky Mountain Front Range to Oklahoma-Texas Panhandle. By Harry Oborne. Abstract . . . 939

Costa Rica, Age of Shale in Amoura-Uscari Area. By William W. Porter II and Paul P. Goudkoff. Abstract 947
Cotton Lake Field, South, Chambers County, Texas. By Joseph M. Wilson . 1898
———. Abstract 931
Cram, Ira H. Memorial of Arthur Albert Wedel 2230
Cretaceous—East Side Sacramento Valley. By W. P. Popenoe. Abstract . . 2095
———, Lower, and Jurassic Formations of Southern Arkansas. By Ralph W. Imlay. Review by W. S. Adkins 329
——— of California, An Introduction to. By Olaf P. Jenkins. Abstract . . 2094
——— of Szechuan, and North Shensi, China, Non-Marine Origin of Petroleum in. Geological Note by C. H. Pan 2058
——— of the Santa Lucia Range. By N. L. Taliaferro. Abstract 2095
———, Upper, Along West Border of San Joaquin Valley, Discussion of Part of. By A. S. Huey and J. W. Daly. Abstract 2096
———, Upper, and Tertiary in New Zealand, Divisions of. By H. J. Finlay and J. Marwick. Review by Burton Wallace Collins 1813
———, Upper, Deposits in Mississippi. By Lloyd William Stephenson and Watson Hiner Monroe. Review by Henry N. Toler 1601
———, Upper, Stratigraphy of West Side of Sacramento Valley South of Willows, Glenn County, California. By James M. Kirby. Abstract 2095
———, West Side Sacramento Valley North of Willows. By Philip W. Reinhart. Abstract 2095
Cretaceous System, The Standard of. By Siemon W. Muller and Hubert G. Schenck. Abstract 2094
Cretaceous Vertebrate Record of California. By Chester Stock. Abstract . . 2094
Crocker Flat Infolded Landslide and Coarse Clastics in Temblor Range, California. By Russell R. Simonson and Max L. Krueger. Abstract. 2097
Croneis, Carey. Micropaleontology—Past and Future 1208, 1597
———. Abstract 936
Cross' La Plata Sandstone, Southwestern Colorado, Correlation of. By Marcus I. Goldman and Arthur C. Spencer 1745
Cross Section of Chester of Illinois Basin. By P. L. Dana and E. H. Scobey . 871
Crude Oil of Gulf Coast, Correlation of Crude Oils with Special Reference to. By Donald C. Barton 561
Crude Oils, Permian, Progress Report on Microscopic Examination of. By W. A. Waldschmidt. Abstract 934
Crude Oils and Stratigraphy, Relationship of, in Parts of Oklahoma and Kansas. By L. M. Neumann *et al.* Research Notes 1801
Crudes, Why They Differ in Value. By H. D. Wilde 1167
———. Abstract 937
Cumberland Plateau, Northern, Oil and Gas Possibilities in. By Kendall E. Born. Abstract 944

Daly, J. W., and Huey, A. S. Discussion of Part of Upper Cretaceous Along West Border of San Joaquin Valley. Abstract 2096
Daly, Reginald Aldworth. Strength and Structure of the Earth. Review by Roland F. Beers 1181
———. Review by William W. Rubey 902
Dana, P. L., and Scobey, E. H. Cross Section of Chester of Illinois Basin . . 871
David, Lore. Miocene Fishes in Well Cores from Torrance in Southern California. Geological Note 319
Davis Sand Lens, Hardin Field, Liberty County, Texas. By S. Russel Casey and Ralph B. Cantrell. Abstract 930
December Meetings of Scientific Societies. The Association Round Table . . 2217
Decker, Charles E. Simpson Group of Arbuckle and Wichita Mountains of Oklahoma 650
Deep Well at Niceville, Okaloosa County, Florida, Micro-paleontology and Stratigraphy of. By R. Hendee Smith 263
DeFord, Ronald K. Permian Correlation Meeting, Centennial, Wyoming, September 2, 1940. Geological Note 429
———. Report of Committee on Publications. The Association Round Table . 972
DeFord, Ronald K., and Riggs, George D. Tansill Formation, West Texas and Southeastern New Mexico 1713

DeGolyer, E. Editor of Elements of the Petroleum Industry, by Many Authors. Review by Wallace E. Pratt 904
Del Valle Area, Geology of. By L. A. Tarbet. Abstract 2096
Del Valle Oil Field, Los Angeles County, California. By R. W. Sherman. Abstract 947
Deltaic Mass, Midway-Wilcox. By H. N. Fisk. Abstract 941
Denison, A. R. Report of Chairman of Resolutions Committee. The Association Round Table 980
Denton, F. R., and Trowbridge, R. M. Developments in East Texas during 1940 1081
———. Abstract 945
Deposition of Free Oil by Sediments Settling in Sea Water. By O. A. Poirier and G. A. Thiel 2170
Deposits, Upper Cretaceous, in Mississippi. By Lloyd William Stephenson and Watson Hiner Monroe. Review by Henry N. Toler 1601
Des Moines, Upper, and Lower Missouri Series, Traverse of, from Jackson County, Missouri, to Appanoose County, Iowa. By L. M. Cline . . . 23
Deussen, Alexander. Twenty-Sixth Annual Meeting, Houston, April 2–4, 1941. Announcement. The Association Round Table 342, 535
Development, after, and before Discovery of Oil Fields. By James C. Kimble. Abstract 2096
——— in Southern Arkansas and Northern Louisiana during 1940. By Joseph Purzer and Warren B. Weeks. Abstract 943
———, Oil and Gas Field, in United States, 1940. By National Oil Scouts and Landmen's Association. Review by Joseph L. Borden 1942
———, Petroleum, and Technology, 1941. By A. I. M. E. Petroleum Division. Review by G. S. Dillé. 1950
Development and Exploration, California, in 1940. by Eugene H. Vallat . . 1159
Developments in Appalachian Area during 1940. By Appalachian Geological Society 1135
——— in East Texas during 1940. By F. R. Denton and R. M. Trowbridge . 1081
———. Abstract 945
——— in Eastern Interior Basin in 1940. By Alfred H. Bell 1114
——— in Michigan in 1940, Oil and Gas. By R. P. Grant. Abstract . . . 944
——— in Mississippi in 1940. By Urban B. Hughes. 1016
———. Abstract 928
——— in 1940, Gulf Coast of Upper Texas and Louisiana, Review of. By O. L. Brace 1004
———. Abstract 928
——— in North Mid-Continent in 1940. By Edward A. Koester 1103
———. Abstract 945
——— in Oklahoma during 1940. By E. F. Shea 1090
——— in Rocky Mountain District in 1940. By C. E. Dobbin 1149
———. Abstract 938
——— in South Texas during 1940. By L. B. Herring. 1037
———. Abstract 931
——— in Southern Arkansas and Northern Louisiana during 1940. By Joseph Purzer and Warren B. Weeks 1024
——— in West Texas and Southeastern New Mexico during 1940. By Taylor Cole, Robert I. Dickey and Edgar Kraus 1044
———. Abstract 933
———, New, in North and West-Central Texas, 1940. By North Texas Geological Society 1064
Devonian and Mississippian Inliers of Southwestern Pennsylvania. Geological Note by Wilson M. Laird 161
Devonian Limestone, Subsurface Strata between Base of Osage Group and Top of, in Illinois. By L. E. Workman and I. T. Sehwade. Abstract . . . 943
Devonian Subsurface Strata in Western Kentucky. By Louise Barton Freeman 668
Dickey, Parke A. Pre-Cretaceous Sediments in Cordillera Oriental of Colombia 1789
———. Review of Petroleum and Genesis of Third Bradford Sand, by Paul D. Krynine. 1413
Dickey, Robert I., Cole, Taylor, and Kraus, Edgar. Developments in West Texas and Southeastern New Mexico during 1940 1044
———. Abstract 933

Dillé, G. S. Review of Petroleum Development and Technology, 1941, by A. I. M. E. Petroleum Division 1950
Discovery, before, and after Development of Oil Fields. By James C. Kimble. Abstract 1096
Discussion 167, 324, 1180, 2071, 2195
——— of Part of Upper Cretaceous Along West Border of San Joaquin Valley. By A. S. Huey and J. W. Daly. Abstract 2096
Distribution of Members, Geographic. The Association Round Table 956
Divisions of the Tertiary of New Zealand. By H. J. Finlay and J. Marwick. Review by Hubert G. Schenck 763
——— of Upper Cretaceous and Tertiary in New Zealand. By H. J. Finlay and J. Marwick. Review by Burton Wallace Collins 1813
Dobbin, C. E. Developments in Rocky Mountain District in 1940 1149
———. Abstract 938
———. Oil-Field Models of Shreveport Geological Society. Geological Note . 1587
Dodge, John F., Pyle, Howard C., and Trostel, Everett G. Estimation by Volumetric Methods of Recoverable Oil and Gas from Sands. 1302
Donnelly, Alden S. High-Pressure Yates Sand Gas Problem, Wasson Field, Yoakum County, West Texas 1880
Donoghue, David. Relation of Initial Production to Ultimate Production of Wells Completed in Smithwick (Gray) Limestone, Breckenridge Field, Stephens County, Texas. Geological Note 1589
Dott, Robert H. Memorial Shale of Pennsylvanian Age, in Oklahoma. Geological Note. 1591
———. Regional Stratigraphy of Mid-Continent 1619
Drilling, Wildcat, in 1940. By Frederic H. Lahee 997, 1938
———. Abstract 938
Drilling-Time Logs, Some, and Their Uses. By Robin Willis. Abstract . . . 2097
Driver, Herschel L. Review of Introduction to Physical Geology, by W. J. Miller 2212
du Toit, Alex. L. Observations on the Evolution of the Pacific Ocean. Review by Victor Oppenheim 1811

Earth, Strength and Structure of. By Reginald Aldworth Daly. Review by Roland F. Beers 1181
———. Review by William W. Rubey 902
East Indian Archipelago, Age of Abyssal Deposits of. Geological Note by Carl C. Branson 320
East Indies, Nederlands, Small Foraminifera from the Late Tertiary of. By L. W. LeRoy. Review by M. C. Israelsky 761
East Texas, Developments in, during 1940. By F. R. Denton and R. M. Trowbridge 1081
East White Point Field, San Patricio and Nueces Counties, Texas, Oligocene Stratigraphy of. By Phil F. Martyn and Charles H. Sample. 1967
———, San Patricio County, Texas, Oligocene Stratigraphy of. By Phil F. Martyn and Charles H. Sample. Abstract 932
Eastern Canada, Possible Future Oil Provinces of. By Geological Survey of Canada, Quebec Bureau of Mines, and Newfoundland Geological Survey 1539, 2194
Eastern Interior Basin, Developments in, in 1940. By Alfred H. Bell . . . 1114
———, Oil and Gas Development in, in 1940. By Alfred H. Bell. Abstract . . 942
Eastern United States, Possible Future Oil Provinces in. By Appalachian Geological Society 1563
Eaton, J. E., Grant, U. S., and Allen, H. B. Miocene of Caliente Range and Environs, California 193
Eaton, J. E., Schenck, H. G., *et al.*, Hedberg, Hollis D., Tomlinson, C. W., and White, R. T. Stratigraphic Nomenclature. Discussion 2195
Eckis, Rollin. Stevens Sand, Southern San Joaquin Valley, California. Abstract 946
Economic Geology, Petroleum Geology, and Petroleum Engineering, Radioactivity Well Logs. Their Use and Application in Fields of. By J. C. Barcklow. Abstract 938
Economic Paleontologists and Mineralogists, Society of, Executive Council. The Association Round Table 927
Economists, Mineral, Needed by the Government 1432

Ector County, Texas, North Cowden Field. By Sam C. Giesey and Frank F. Fulk 593
Editor, Report of. By W. A. Ver Wiebe. The Association Round Table . . . 961
Edna Gas Field, Jackson County, Texas. By M. M. Kornfeld and C. R. Steinberger 104
Effect of Acidizing Oil Reservoirs Composed of Sands, Laboratory and Field Observations of. By P. E. Fitzgerald, F. R. James and Ray L. Austin . 850
———. Abstract 937
Effective Porosity of Gas Fields in Jackson County, Missouri. By Glenn G. Bartle. Abstract 947
———. Geological Note by Glenn G. Bartle 1405
Elements of the Petroleum Industry. By Many Authors. Review by Wallace E. Pratt 904
Ellenburger Formation in West Texas, Subsurface Study of. By Taylor Cole. Abstract 934
——— of Texas, Correlation of Subsurface Sections with Outcrops of. By Leo Hendricks. Abstract 943
Ellenburger Structure Map of Central Texas. By A. I. Levorsen. Research Notes 1600
Ellisor, Alva C. Review of The Tertiary Foraminifera of Porto Rico, by J. J. Galloway and Caroline E. Heminway 1810
Ellsworth-Coldwater-Antrim Shale Formations in Michigan. By Eleanor Tarbell 724
Emery, K. O., and Shepard, Francis P. Submarine Topography off the California Coast: Canyons and Tectonic Interpretation. Review by John L. Ferguson 1940
Emrick, D. G. Memorial of Samuel W. Riter 2100
Eocene of Texas Gulf Coastal Plain, Sedimentary Cycles in. By H. B. Stenzel. Abstract 933
Eola Oil Field, Avoyelles Parish, Louisiana, Geology of. By Fred W. Bates 1363, 1597
Estimating Oil Reserves, Introduction to Technique for. By Park J. Jones. Abstract 944
———, This Matter of. Geological Note by Frederic H. Lahee 164
Estimation by Volumetric Methods of Recoverable Oil and Gas from Sands. By John F. Dodge, Howard C. Pyle, and Everett G. Trostel 1302
Evans, Charles S. Review of Natural Gas in Brantford Area, Ontario, by J. F. Caley 1950
Evaporite Salts in Green River Basin, Wyoming, Exploration for. Geological Note by R. G. Greene 1799
Evolution of the Pacific Ocean, Observations on. By Alex. L. du Toit. Review by Victor Oppenheim 1811
Excerpts from the Fiftieth Anniversary Volume of the Geological Society of America 2076
Executive Committee, Association. The Association Round Table 927
——— (Council), Society of Economic Paleontologists and Mineralogists. The Association Round Table 927
——— (Officers), Houston Geological Society. The Association Round Table . 927
———, Society of Exploration Geophysicists. The Association Round Table . 927
Executive Committee Meetings. The Association Round Table 954
Exercise on Amount of Source Bed Required to Furnish Oklahoma City Oil Pool. By Roy L. Ginter 1706
Experiments with Lights, Shadows, and Contours, and the Resulting Shadowgraphic Contour Maps. By Robert F. Imbt 2161
Exploration for Evaporite Salts in Green River Basin, Wyoming. Geological Note by R. G. Greene 1799
Exploration and Development, California, in 1940. By Eugene H. Vallat . . 1159
Exploration Geophysicists, Society of, Executive Committee. The Association Round Table 927
———, Society of, Titles of Papers on Program of. The Association Round Table 949
Exploration Geophysics. By J. J. Jakosky. Review by L. W. Blau 170
Exploration Work in California during 1940. By Eugene H. Vallat. Abstract . 946
Extension, Northwest, of Inglewood Field. By Robin Willis. Abstract . . . 2097

Faulting, Post-Appalachian, in Western Kentucky. By Roger Rhoades and Alvin J. Mistler 2046

———, Thrust, and Coarse Clastics in Temblor Range, California. By F. S. Hudson and G. H. White 1327
Faults, Trace-Slip. By R. H. Beckwith 2182
Faunal Studies of Navarro Group of Texas, Summary of. By Lloyd William Stephenson 637
Ferguson, John L. Review of Geophysical Prospecting for Oil, by L. L. Nettleton 328
———. Review of Geophysics, 1940, by the American Institute of Mining and Metallurgical Engineers 760
———. Review of Submarine Topography off the California Coast: Canyons and Tectonic Interpretation, by Francis P. Shepard and K. O. Emery . . . 1940
Ferrando, Al, and Richardson, H. T. Barataria Field, Jefferson Parish, Louisiana. Geological Note 322
Field and Laboratory Observations of Effect of Acidizing Oil Reservoirs Composed of Sands. By P. E. Fitzgerald, F. R. James and Ray L. Austin . . 850
———. Abstract 937
Field Experience, Where Should Young Graduates in Petroleum Geology Acquire It? Discussion by Frederic H. Lahee 167
Field Geology, Future of. Discussion by R. Dana Russell. 324
Field Trips 780, 996, 1200, 1431, 1838
Fifth Dimension in the Oil Industry. By J. Edgar Pew 1283
Fiftieth Anniversary Volume of the Geological Society of America. Geology, 1888–1938. Review by Charles W. Tomlinson 2075
Finances. The Association Round Table 953, 957
Financial Aid, Grants of. The Association Round Table 974
Financial Statement, Division of Paleontology and Mineralology, for 1940. The Association Round Table 453
Financial Statement for 1940. The Association Round Table 448
Finlay, H. J., and Marwick, J. Divisions of Upper Cretaceous and Tertiary in New Zealand. Review by Burton Wallace Collins 1813
———. The Divisions of the Tertiary of New Zealand. Review by Hubert G. Schenck 763
Fisher, Barney. La Rosa Field, Refugio County, Texas 300
Fishes, Miocene, in Well Cores from Torrance in Southern California. Geological Note by Lore David 319
Fisk, H. N. Midway-Wilcox Deltaic Mass. Abstract 941
Fitzgerald, P. E., James, F. R., and Austin, Ray L. Laboratory and Field Observations of Effect of Acidizing Oil Reservoirs Composed of Sands 850
———. Abstract 937
Florida, Micropaleontology and Stratigraphy of a Deep Well at Niceville, Okaloosa County. By R. Hendee Smith 263
Florida Academy of Sciences, Proceedings of, for 1939. Review by Robert B. Campbell 168
Foraminifera, Carboniferous, of the Samara Bend. By D. Rauser-Černoussova, G. Beljaev, and E. Reitlinger. Review by Siemon Wm. Muller and Hubert G. Schenck 1943
———, Small, from Late Tertiary of the Nederlands East Indies. By L. W. LeRoy. Review by M. C. Israelsky 761
———, Tertiary, of Porto Rico. By J. J. Galloway and Caroline E. Heminway. Review by Alva C. Ellisor 1810
Foreign Developments during 1939 and 1940. By Basil B. Zavoico. Abstract . 937
Foreword to Possible Future Oil Provinces of the United States and Canada. By A. I. Levorsen 1433
Formation Samples from Gun Perforators. Geological Note by J. T. Richards . 752
Fort Bend County, Texas, Clodine Field. Geological Note by Jack O. Colle . 2057
Fossiliferous Localities of Midway Group in Louisiana. Geological Note by Rufus J. LeBlanc and John O. Barry 734
Franciscan Knoxville Problem. By N. L. Taliaferro. Abstract 2095
Free Oil, Deposition of, by Sediments Settling in Sea Water. By O. A. Poirier and G. A. Thiel 2170
Freeman, Louise Barton. Devonian Subsurface Strata in Western Kentucky . 668
Freezeout Mountain-Bald Mountain Area, Carbon County, Wyoming, Geology of. By Milan D. Maravich 883
Fresh-Water Lakes, Sediments of. By W. H. Twenhofel and V. E. McKelvey . 826

Fulk, Frank F., and Giesey, Sam C. North Cowden Field, Ector County, Texas 593
Future of Field Geology. Discussion by R. Dana Russell 324
Future of Geophysics. By W. T. Born 1256
Future, Possible, Oil Provinces in Alaska. By Philip S. Smith 1440
———, Possible, Oil Provinces in Eastern United States. By Appalachian Geological Society 1563
———, Possible, Oil Provinces in Pacific Coast States. By Pacific Section of American Association of Petroleum Geologists 1457
———, Possible, Oil Provinces in Rocky Mountain Region. By Rocky Mountain Association of Petroleum Geologists. 1469
———, Possible, Oil Provinces in Western Canada. By Alberta Society of Petroleum Geologists 1447
———, Possible, Oil Provinces of Eastern Canada. By Geological Survey of Canada, Quebec Bureau of Mines, and Newfoundland Geological Survey . 1539, 2194
———, Possible, Oil Provinces of Northern Mid-Continent States. By Texas Geological Society 1508
———, Possible, Oil Provinces of Southeastern United States. By Mississippi Geological Society 1575
———, Possible, Oil Provinces of the United States and Canada. Foreword. By A. I. Levorsen 1433
———, Possible, Oil Provinces of West Texas. By West Texas Geological Society 1527

Gallie, J. F. South Texas Geological Society Student Award. The Association Round Table 1607
Galliher, E. W., and Atwill, E. R. Progress of Stratigraphic Studies in California. Abstract 946
Galloway, J. J., and Heminway, Caroline E. The Tertiary Foraminifera of Porto Rico. Review by Alva C. Ellisor. 1810
Gardner, Julia. Analysis of Midway Fauna of Western Gulf Province . . . 644
Gas, Natural, with Regard to Its Place in National Defense. By N. C. McGowen 1291
Gas and Oil, Recoverable, from Sands, Estimation by Volumetric Methods of. By John F. Dodge, Howard C. Pyle, and Everett G. Trostel 1302
Gas and Oil Developments in Michigan in 1940. By R. P. Grant 1125
———. Abstract 944
Gas and Oil Field Development in United States, 1940. By National Oil Scouts and Landmen's Association. Review by Joseph L. Borden 1942
Gas and Oil Fields, Major Tectonic Provinces of Southern Oklahoma and Their Relation to. By E. A. Paschal 1
Gas Fields in Jackson County, Missouri, Effective Porosity of. By Glenn G. Bartle. Abstract 947
———. Geological Note by Glenn G. Bartle 1405
Gay-Spencer-Richardson Oil and Gas Trend in West Virginia. By E. T. Heck. Abstract 942
Genesis and Petroleum of the Third Bradford Sand. By Paul D. Krynine. Review by Parke A. Dickey 1413
Geochemistry of Natural Gas in Appalachian Province. By Paul H. Price and A. J. W. Headlee. Abstract 942
Geographic Distribution of Members. The Association Round Table . . . 956
Geologic Names and Correlations, Report of Committee on. By John G. Bartram The Association Round Table 977
Geological Notes . 161, 318, 424, 734, 898, 1175, 1405, 1587, 1796, 1934, 2057, 2194
——— on Oak Canyon Oil Field. By Wayne Loel, R. W. Clark, and Paul P. Goudkoff. Abstract 2096
Geological Society of America, Excerpts from the Fiftieth Anniversary Volume of 2076
———, Fiftieth Anniversary Volume of. Geology, 1888–1938. Review by Charles W. Tomlinson 2075
———, Remarks at the Fifty-Third Annual Meeting of. By L. C. Snider. The Association Round Table 916
Geological Survey of Canada, Quebec Bureau of Mines, and Newfoundland Geological Survey. Possible Future Oil Provinces of Eastern Canada . . 1539, 2194
Geology, 1888–1938. Fiftieth Anniversary Volume of the Geological Society of America. Review by Charles W. Tomlinson 2075

———, Field, Future of. Discussion by R. Dana Russell 324
——— of Bartelso Oil Field, Clinton County, Illinois. By James L. Carlton. Abstract 944
——— of Del Valle Area. By L. A. Tarbet. Abstract 2096
——— of Eola Oil Field, Avoyelles Parish, Louisiana. By Fred W. Bates . . 1363
——— of Freezeout Mountain-Bald Mountain Area, Carbon County, Wyoming. By Milan D. Maravich 883
——— of Mississippi, Notes on. By Tom McGlothlin. Abstract 929
——— of Southern Part of La Barge Region, Lincoln County, Wyoming. By A. J. Bertagnolli, Jr. 1729
——— of Wasson Field, Gaines and Yoakum Counties, Texas. By W. T. Schneider. Abstract 933
——— of Wind River Mountains, Wyoming. By E. B. Branson and C. C. Branson 120
———, Physical, Introduction to. By W. J. Miller. Review by Herschel L. Driver 2212
———, Tertiary, of Australia. By F. A. Singleton. Review by Burton Wallace Collins 1813
Geology Students, Survey of. By A. I. Levorsen. Research Notes 910
Geophysical Prospecting for Oil. By L. L. Nettleton. Review by John L. Ferguson 328
Geophysics, Exploration. By J. J. Jakosky. Review by L. W. Blau 170
———, 1940. By the American Institute of Mining and Metallurgical Engineers. Review by John L. Ferguson 760
———, the Future of. By W. T. Born 1256
Giesey, Sam C., and Fulk, Frank F. North Cowden Field, Ector County, Texas 593
Ginter, Roy L. Exercise on Amount of Source Bed Required to Furnish Oklahoma City Oil Pool 1706
Glenn County, California, Upper Cretaceous Stratigraphy of West Side of Sacramento Valley South of Willows. By James M. Kirby. Abstract . . . 2095
Glockzin, Albert R., and Roy, Chalmer J. Tentative Correlation Chart of Gulf Coast. Geological Note 742
Gold, Silver, and Other Elements in Salt-Dome Cap Rocks. Geological Note by Marcus A. Hanna and Albert G. Wolf 750
Goldman, Marcus I., and Spencer, Arthur C. Correlation of Cross' La Plata Sandstone, Southwestern Colorado 1745
Goodman, Clark, and Whitehead, W. L. Progress Report on Radioactivity of Petroleum and Natural Gas. The Association Round Table 975
Goudkoff, Paul P., and Porter II, William W. Age of Shale in Amoura-Uscari Area, Costa Rica. Abstract 947
Goudkoff, Paul P., Loel, Wayne, and Clark, R. W. Geological Notes on Oak Canyon Oil Field. Abstract 2096
Government, Mineral Economists Needed by 1432
Grabau, A. W. The Rhythm of the Ages. Review by Edwin Kirk 1421
Graduates in Petroleum Geology, Young, Where Should They Acquire Field Experience? Discussion by Frederic H. Lahee 167
Grant, R. P. Oil and Gas Developments in Michigan in 1940 1125
———. Abstract 944
Grant, U. S., Eaton, J. E., and Allen, H. B. Miocene of Caliente Range and Environs, California 193
Grants of Financial Aid. The Association Round Table 974
Gravity Anomalies, Relationship between Some Types of, and Structure. By Robert H. Miller. Abstract 2097
Graywackes and the Petrology of Bradford Oil Field, Pennsylvania. Discussion by Paul D. Krynine 2071
Green River Basin, Wyoming, Exploration for Evaporite Salts in. Geological Note by R. G. Greene 1799
Greene, R. G. Exploration for Evaporite Salts in Green River Basin, Wyoming. Geological Note 1799
Ground-Water Motion, Theory of. By M. King Hubbert. Review by L. K. Wenzel 1418
Ground-Water Resources of Kansas. By Raymond C. Moore. Review by Hugh McClellan 1412
Guidebooks on Colorado and Rocky Mountain Region 2092

Gulf Coast, Correlation of Crude Oils with Special Reference to Crude Oil of. By Donald C. Barton . . . 561
———, Marine Sedimentation and Oil Accumulation on. By Dorothy A. Jung and Doris S. Malkin. Abstract . . . 930
———, Marine Sedimentation and Oil Accumulation on. I. Progressive Marine Overlap. By Doris S. Malkin and Dorothy A. Jung . . . 2010
——— of Upper Texas and Louisiana, Review of Developments in 1940. By O. L. Brace . . . 1004
———. Abstract . . . 928
———, Tentative Correlation Chart of. Geological Note by Chalmer J. Roy and Albert R. Glockzin . . . 742
———, Texas, Basal Vicksburg Sand of. By A. N. Wilson. Abstract . . . 931
Gulf Coast Area, Abstracts of Papers on. The Association Round Table . . . 928
Gulf Coast Region of Texas and Louisiana, Résumé on Sedimentation in. By L. W. Storm. Abstract . . . 936
Gulf Coast Tertiary Sediments, Comparative Study of Origin and Distribution of. By Carl B. Richardson. Abstract . . . 929
Gulf Coastal Plain, Texas, Sedimentary Cycles in Eocene of. By H. B. Stenzel. Abstract . . . 933
Gulf Province, Western, Analysis of Midway Fauna of. By Julia Gardner . . . 644
Gulley, M. G. Memorial of Thurman H. Myers . . . 347
Gun Perforators, Formation Samples from. Geological Note by J. T. Richards . . . 752
Gutenberg, G. Editor of Internal Constitution of the Earth. Review by Robert L. Bates . . . 172

Halbouty, Michel T. Oil and Gas Stratigraphic Reservoirs in University Oil Field, East Baton Rouge Parish, Louisiana. Abstract. . . . 930
Hale, Lucille. Study of Sedimentation and Stratigraphy of Lower Mississippian in Western Michigan . . . 713
Hall, George Martin. Memorial by Joseph T. Singewald, Jr. . . . 1828
Ham, W. E., and Merritt, C. A. Pre-Cambrian Zeolite-Opal Sediments in Wichita Mountains, Oklahoma . . . 287
Handley, Howard Walter. Memorial by Verner Jones . . . 184
Hanna, Marcus A. Review of Methods of Study of Sediments, by W. H. Twenhofel and S. A. Tyler . . . 1420
Hanna, Marcus A., and Wolf, Albert G. Gold, Silver, and Other Elements in Salt-Dome Cap Rocks. Geological Note . . . 750
Hardin Field, Liberty County, Texas, Davis Sand Lens. By S. Russel Casey and Ralph B. Cantrell. Abstract . . . 930
Harrell, D. C. Mississippi Geological Society Fourth Annual Field Trip, December 6–8, 1940. The Association Round Table . . . 181
Hawkins Field, Wood County, Texas. Geological Note by H. J. McLellan . . . 898
Headlee, A. J. W., and Price, Paul H. Geochemistry of Natural Gas in Appalachian Province. Abstract . . . 942
Heart Mountain and South Fork Thrusts, Park County, Wyoming. By William G. Pierce . . . 2021
Heck, E. T. Gay-Spencer-Richardson Oil and Gas Trend in West Virginia. Abstract . . . 942
Hedberg, Hollis D., Schenck, H. G., *et al.*, Tomlinson, C. W., Eaton, J. E., and White, R. T. Stratigraphic Nomenclature. Discussion . . . 2195
Heminway, Caroline E., and Galloway, J. J. The Tertiary Foraminifera of Porto Rico. Review by Alva C. Ellisor. . . . 1810
Hendricks, Leo. Correlation of Subsurface Sections with Outcrops of Ellenberger Formation of Texas. Abstract . . . 943
Herring, L. B. Developments in South Texas during 1940 . . . 1037
———. Abstract . . . 931
Hexactinellida, Paleozoic and Recent Branching; The Titusvilliidae. By Kenneth E. Caster. Review by W. A. Ver Wiebe . . . 2082
High-Pressure Yates Sand Gas Problem, Wasson Field, Yoakum County, West Texas. By Alden S. Donnelly . . . 1880
Hill, Robert Thomas. Memorial by W. E. Wrather . . . 2221
Hilseweck, W. J. Walnut Bend Pool of Cooke County, Texas. Abstract . . . 941

Honorary Member, Walter George Woolnough. By J. T. Richards. The Association Round Table 1954
Hoover, J. B. Memorial of Otto Leatherock 2101
Hoskins, Baker, Jr. Memorial by H. V. Tygrett 2228
Houston Geological Society Officers. The Association Round Table 927
Houston Geological Society Student Awards. The Association Round Table . 1606
Hubbert, M. King. The Theory of Ground-Water Motion. Review by L. K. Wenzel 1418
Hudson, F. S., and White, G. H. Thrust Faulting and Coarse Clastics in Temblor Range, California 1327
Huey, A. S., and Daly, J. W. Discussion of Part of Upper Cretaceous Along West Border of San Joaquin Valley. Abstract 2096
Hughes, Urban B. Developments in Mississippi in 1940 1016
———. Abstract 928

Ickes, Eugene Law. Memorial by Max L. Krueger 1962
Illinois, Geology of Bartelso Oil Field, Clinton County, By James L. Carlton. Abstract 944
———, Subsurface Strata between Base of Osage Group and Top of Devonian Limestone in. By L. E. Workman and I. T. Sehwade. Abstract. . . . 943
Illinois Basin, Cross Section of Chester of. By P. L. Dana and E. H. Scobey . 871
Imbt, Robert F. Experiments with Lights, Shadows, and Contours, and the Resulting Shadowgraphic Contour Maps 2161
Imlay, Ralph W. Lower Cretaceous and Jurassic Formations of Southern Arkansas. Review by W. S. Adkins 329
Improved Method of Handling Microfilm Copy. Geological Note by H. T. U. Smith 2068
Industry and Science, Temperature, Its Measurement and Control in. A Symposium. Review by Roger C. Wells 1416
Infolded Landslide, Crocker Flat, and Coarse Clastics in Temblor Range, California. By Russell R. Simonson and Max L. Krueger. Abstract . . . 2097
Inglewood Field, Northwest Extension of. By Robin Willis. Abstract . . . 2097
Inglewood Oil Field, Recently Discovered Middle Miocene Production in. By A. F. Woodward. Abstract 947
Initial Daily Production of Wells in Burbank and South Burbank Oil Fields, Oklahoma, Significance of. Geological Note by N. Wood Bass 1175
Initial Production, Relation of, to Ultimate Production of Wells Completed in Smithwick (Gray) Limestone, Breckenridge Field, Stephens County, Texas. Geological Note by David Donoghue 1589
Inliers, Devonian and Mississippian, of Southwestern Pennsylvania. Geological Note by Wilson M. Laird 161
Insoluble Residue Study Group, Midland, Texas. Geological Note by Taylor Cole 318
Institute of Petroleum. Annual Reviews of Petroleum Technology. Review by J. E. Brantly 327
Interior Basin, Eastern, Development in, in 1940. By Alfred H. Bell . . . 1114
Internal Constitution of the Earth. Edited by G. Gutenberg. Review by Robert L. Bates. 172
International Relations, Oil in. By Walter H. Voskuil 353
Introduction to Physical Geology. By W. J. Miller. Review by Herschel L. Driver 2212
——— to Technique for Estimating Oil Reserves. By Park J. Jones. Abstract . 944
——— to the Cretaceous of California. By Olaf P. Jenkins. Abstract 2094
Iowa, Appanoose County, Traverse of Upper Des Moines and Lower Missouri Series from Jackson County, Missouri, to. By L. M. Cline 23
Israelsky, M. C. Review of Small Foraminifera from the Late Tertiary of the Nederlands East Indies, by L. W. LeRoy 761

Jackson County, Missouri, Effective Porosity of Gas Fields in. Geological Note by Glenn G. Bartle 1405
———, Missouri, Traverse of Upper Des Moines and Lower Missouri Series from, to Appanoose County, Iowa. By L. M. Cline 23

———, Texas, Edna Gas Field. By M. M. Kornfeld and C. R. Steinberger . 104
Jakosky, J. J. Exploration Geophysics. Review by L. W. Blau 170
James, F. R., Fitzgerald, P. E., and Austin, Ray L. Laboratory and Field Observations of Effect of Acidizing Oil Reservoirs Composed of Sands . . 850
———. Abstract 937
Japanese Islands, Paleozoic Formations of. By Hisakatsu Yabe. Review by Hubert G. Schenck 767
Jefferson Parish, Louisiana, Barataria Field. Geological Note by Al Ferrando and H. T. Richardson 322
Jenkins, Olaf P. An Introduction to the Cretaceous of California. Abstract . . 2094
Jennings Dome, Acadia Parish, Louisiana, Subsurface Study of. By C. B. Roach. Abstract 929
Johnson, Helgi, Newfoundland. Possible Future Oil Provinces of Eastern Canada 1558
Jones, I. W. Quebec. Possible Future Oil Provinces of Eastern Canada . . . 1555
Jones, Park J. Introduction to Technique for Estimating Oil Reserves. Abstract 944
Jones, Verner. Memorial of Howard Walter Handley 184
Jung, Dorothy A., and Malkin, Doris S. Marine Sedimentation and Oil Accumulation on Gulf Coast. I. Progressive Marine Overlap 2010
———. Abstract 930
Jurassic and Lower Cretaceous Formations of Southern Arkansas. By Ralph W. Imlay. Review by W. S. Adkins 329

Kamb, H. R., and Packard, S. A. Olla Field, La Salle Parish, Louisiana. Geological Note 747
Kansas, Ground-Water Resources of. By Raymond C. Moore. Review by Hugh McClellan 1412
———, Migration of Oil from Arbuckle Limestone into Chattanooga Shale in Chetopa Oil Pool, Labette County. Geological Note by G. E. Abernathy . 1934
———, Southeastern, and North Central and Northeastern Oklahoma, Occurrence of Oil and Gas in Pennsylvanian Sands in. By Luther E. Kennedy. Abstract 945
———, Subsurface Mississippian Rocks of. By Wallace Lee. Review by Hugh McClellan 1410
Kansas and Oklahoma, Relationship of Crude Oils and Stratigraphy in Parts of. By L. M. Neumann *et al.* Research Notes 1801
Kansas Geological Society Field Conference, August 27–31 1617
———, Field Trip, August 27–31. Field Trip 1200, 1431
Kansas Uplift, Central, Stream Channels Applied to Arbuckle of. By J. A. Mull. Abstract 946
Kay, G. Marshall. Classification of Artinskian Series in Russia 1396
Kennedy, Luther E. Occurrence of Oil and Gas in Pennsylvanian Sands in North Central and Northeastern Oklahoma and Southeastern Kansas. Abstract . 945
Kentucky, Western, Devonian Subsurface Strata in. By Louise Barton Freeman 668
———, Western, Post-Appalachian Faulting in. By Roger Rhoades and Alvin J. Mistler 2046
Kimball, E. W. Memorial of Jesse Elmore Simmons 1610
Kimble, James C. Oil Fields—before Discovery and after Development. Abstract 2096
Kirk, Edwin. Review of The Rhythm of the Ages, by A. W. Grabau 1421
Knoxville Problem, Franciscan. By N. L. Taliaferro. Abstract 2095
Koester, Edward A. Developments in North Mid-Continent in 1940 1103
———. Abstract 945
Kornfeld, M. M., and Steinberger, C. R. Edna Gas Field, Jackson County, Texas 104
Kraus, Edgar, Cole, Taylor, and Dickey, Robert I. Developments in West Texas and Southeastern New Mexico. Abstract 933
———. Developments in West Texas and Southeastern New Mexico during 1940 1044
Krueger, Max L. Memorial of Eugene Law Ickes 1962
Krueger, Max L., and Simonson, Russell R. Crocker Flat Infolded Landslide and Coarse Clastics in Temblor Range, California. Abstract . . . 2097
Krynine, Paul D. Graywackes and the Petrology of Bradford Oil Field, Pennsylvania. Discussion 2071
———. Petroleum and Genesis of Third Bradford Sand. Review by Parke A. Dickey 1413

La Barge Region, Lincoln County, Wyoming, Geology of Southern Part of. By A. J. Bertagnolli, Jr. . . . 1729
La Plata Sandstone, Cross', Southwestern Colorado, Correlation of. By Marcus I. Goldman and Arthur C. Spencer . . . 1745
La Rosa Field, Refugio County, Texas. By Barney Fisher . . . 300
La Salle Parish, Louisiana, Olla Field. Geological Note by S. A. Packard and H. R. Kamb . . . 747
Labette County, Kansas, Migration of Oil from Arbuckle Limestone into Chattanooga Shale in Chetopa Oil Pool. Geological Note by G. E. Abernathy 1934
Laboratory and Field Observations of Effect of Acidizing Oil Reservoirs Composed of Sands. By P. E. Fitzgerald, F. R. James, and Ray L. Austin . . 850
———. Abstract . . . 937
Lafferty, Robert C. Central Basin of Appalachian Geosyncline . . . 781
Lahee, Frederic H. This Matter of Estimating Oil Reserves. Geological Note . 164
———. Where Should Young Graduates in Petroleum Geology Acquire Field Experience? Discussion . . . 167
———. Wildcat Drilling in 1940 . . . 997, 1938
———. Abstract . . . 938
Laird, Wilson M. Devonian and Mississippian Inliers of Southwestern Pennsylvania. Geological Note. . . . 161
Lamar County, Mississippi, Tatum Salt Dome. Geological Note by Cecil L. Morgan . . . 424
Landmen's and National Oil Scouts Association. Oil and Gas Field Development in United States 1940. Review by Joseph L. Borden . . . 1942
Landslide, Crocker Flat Infolded, and Coarse Clastics in Temblor Range, California. By Russell R. Simonson and Max L. Krueger. Abstract . . . 2097
Lang, Walter B. New Source for Sodium Sulphate in New Mexico . . . 152
Late Cenozoic Deposits of Texas Coastal Plain between Brazos River and Rio Grande. By A. W. Weeks. Abstract . . . 932
Late Tertiary of the Nederlands East Indies, Small Foraminifera from. By L. W. LeRoy. Review by M. C. Israelsky . . . 761
Lateral Gradation in Seven Rivers Formation, Rocky Arroyo, Eddy County, New Mexico. By Robert L. Bates. Abstract . . . 935
Laudon, L. R., and Bowsher, A. L. Mississippian Formations of Sacramento Mountains, New Mexico . . . 2107
———. Abstract . . . 935
Leatherock, Otto. Memorial by J. B. Hoover . . . 2101
LeBlanc, R. J. Correlation of Upper Midway Fauna of Louisiana. Abstract . 941
LeBlanc, Rufus J., and Barry, John O. Fossiliferous Localities of Midway Group in Louisiana. Geological Note . . . 734
Lee, Wallace. Subsurface Mississippian Rocks of Kansas. Review by Hugh McClellan . . . 1410
LeRoy, L. W. Small Foraminifera from the Late Tertiary of the Nederlands East Indies. Review by M. C. Israelsky . . . 761
Levorsen, A. I. Announcement. Research Notes . . . 177
———. Ellenburger Structure Map of Central Texas. Research Notes . . . 1600
———. Foreword to Possible Future Oil Provinces of the United States and Canada . . . 1433
———. Report of Chairman of Research Committee. The Association Round Table . . . 972
———. Report of Representative on Division of Geology and Geography of National Research Council, 1940–1941. The Association Round Table . 977
———. Research Committee Conferences. Research Notes . . . 337
———. Research Dinner—Round Table Discussion. Research Notes . . . 177
———. Survey of Geology Students. Research Notes . . . 910
———. The Origin of Oil. Research Notes . . . 2086
Lewis, Frank E. Position of San Andres Group, West Texas and New Mexico . 73
Lights, Shadows, and Contours, Experiments with, and the Resulting Shadowgraphic Contour Maps. By Robert F. Imbt . . . 2161
Lincoln County, Wyoming, Geology of Southern Part of La Barge Region. By A. J. Bertagnolli, Jr. . . . 1729
Loel, Wayne, Clark, R. W., and Goudkoff, Paul P. Geological Notes on Oak Canyon Oil Field. Abstract . . . 2096
Logging, Radioactivity, Applications of. By William L. Russell. Abstract . . 938

Logs, Some Drilling-Time, and Their Uses. By Robin Willis. Abstract . . . 2097
Los Angeles County, California, Del Valle Oil Field. By R. W. Sherman. Abstract . . . 947
Louisiana, Barataria Field, Jefferson Parish. Geological Note by Al Ferrando and H. T. Richardson . . . 322
———, Correlation of Upper Midway Fauna of. By R. J. LeBlanc. Abstract . 941
———, Correlation of Wilcox Faunal Units of. By J. O. Barry. Abstract . . . 941
———, Fossiliferous Localities of Midway Group in. Geological Note by Rufus J. LeBlanc and John O. Barry . . . 734
———, Geology of Eola Oil Field, Avoyelles Parish. By Fred W. Bates . . 1363, 1597
———, Northern, and Southern Arkansas, Developments in, during 1940. By Joseph Purzer and Warren B. Weeks . . . 1024
———, Abstract . . . 943
———, Northwestern, Midway Microfauna of. Geological Note by Grover Murray, Jr. . . . 738
———, Oil and Gas Stratigraphic Reservoirs in University Oil Field, East Baton Rouge Parish. By Michel T. Halbouty. Abstract . . . 930
———, Olla Field, La Salle Parish. Geological Note by S. A. Packard and H. R. Kamb . . . 747
———, Subsurface Study of Jennings Dome, Acadia Parish. By C. B. Roach. Abstract . . . 929
Louisiana and Texas, Résumé on Sedimentation in Gulf Coast Region of. By L. W. Storm. Abstract . . . 936
Louisiana and Upper Texas, Gulf Coast of, Review of Developments in 1940. By O. L. Brace . . . 1004
Lower Cretaceous and Jurassic Formations of Southern Arkansas. By Ralph W. Imlay. Review by W. S. Adkins . . . 329
Lower Mississippian in Western Michigan, Study of Sedimentation and Stratigraphy of. By Lucille Hale . . . 713
Lower Missouri and Upper Des Moines Series from Jackson County, Missouri, to Appanoose County, Iowa, Traverse of. By L. M. Cline . . . 23

McClellan, Hugh. Review of Ground-Water Resources of Kansas, Raymond C. Moore . . . 1412
———. Review of Subsurface Mississippian Rocks of Kansas, by Wallace Lee . 1410
McGlothlin, Tom. Notes on Geology of Mississippi. Abstract . . . 929
McGowen, N. C. Natural Gas with Regard to Its Place in National Defense . 1291
McKelvey, V. E., and Twenhofel, W. H. Sediments of Fresh-Water Lakes . . 826
McLellan, H. J. Hawkins Field, Wood County, Texas. Geological Note . . . 898
Major Tectonic Provinces of Southern Oklahoma and Their Relation to Oil and Gas Fields. By E. A. Paschal . . . 1
Malkin, Doris S., and Jung, Dorothy A. Marine Sedimentation and Oil Accumulation on Gulf Coast. Abstract . . . 930
———. Marine Sedimentation and Oil Accumulation on Gulf Coast. I. Progressive Marine Overlap . . . 2010
Map of Central Texas, Ellenburger Structure. By A. I. Levorsen. Research Notes . . . 1600
Maravich, Milan D. Geology of Freezeout Mountain-Bald Mountain Area, Carbon County, Wyoming . . . 883
Marine Overlap, Progressive. Marine Sedimentation and Oil Accumulation on Gulf Coast. I. By Doris A. Malkin and Dorothy A. Jung . . . 2010
Marine Sedimentation and Oil Accumulation on Gulf Coast. By Dorothy A. Jung and Doris S. Malkin. Abstract . . . 930
———. I. Progressive Marine Overlap. By Doris S. Malkin and Dorothy A. Jung . . . 2010
Martyn, Phil F., and Sample, Charles H. Oligocene Stratigraphy of East White Point Field, San Patricio and Nueces Counties, Texas . . . 1967
———. Abstract . . . 932
Marwick, J., and Finlay, H. J. Divisions of Upper Cretaceous and Tertiary in New Zealand. Review by Burton Wallace Collins . . . 1813
———. The Divisions of the Tertiary of New Zealand. Review by Hubert G. Schenck . . . 763
Meetings of Scientific Societies in December. The Association Round Table . 2217

Membership Applications 178, 338, 444, 550, 772, 911, 1186, 1425, 1605, 1820, 1961, 2087, 2106, 2216
Membership Data. The Association Round Table 955
Membership List, March 6, 1941. The Association Round Table 457
———, Supplementary, September 1, 1941. The Association Round Table . 1821
Memorial 184, 346, 546, 1610, 1828, 1962, 2100, 2221
Memorial Shale of Pennsylvanian Age, in Oklahoma. Geological Note by Robert H. Dott 1591
Merritt, C. A., and Ham, W. E. Pre-Cambrian Zeolite-Opal Sediments in Wichita Mountains, Oklahoma 287
Method, Improved, of Handling Microfilm Copy. Geological Note by H. T. U. Smith 2068
Methods of Study of Sediments. By W. H. Twenhofel and S. A. Tyler. Review by Marcus A. Hanna 1420
Michigan, Antrim-Ellsworth-Coldwater Shale Formations in. By Eleanor Tarbell 724
———, Oil and Gas Developments in, in 1940. By R. P. Grant 1125
———. Abstract 944
———, Shoestring Sand Gas Fields of. By Max W. Ball, T. J. Weaver, and Douglas S. Ball. Abstract 942
———, Western, Study of Sedimentation and Stratigraphy of Lower Mississippian in. By Lucille Hale 713
Microfauna, Midway, of Northwestern Louisiana. Geological Note by Grover Murray, Jr. 738
Microfaunas of Niobrara and Benton in Foothills of Northern Colorado. By W. C. Toepelman. Abstract 940
Microfilm Copy. Improved Method of Handling. Geological Note by H. T. U. Smith 2068
Micropaleontology—Past and Future. By Carey Croneis 1208, 1597
———. Abstract 936
Micropaleontology and Stratigraphy of a Deep Well at Niceville, Okaloosa County, Florida. By R. Hendee Smith 263
Microscopic Examinations of Permian Crude Oils, Progress Report on. By W. A. Waldschmidt. Abstract 934
Mid-Continent, North, Developments in, in 1940. By Edward A. Koester . . 1103
———. Abstract 945
———, Regional Stratigraphy of. By Robert H. Dott 1619
Mid-Continent Region, North, Abstracts of Papers on. The Association Round Table 945
———, South, Abstracts of Papers on. The Association Round Table . . . 940
Mid-Continent States, Northern, Possible Future Oil Provinces of. By Tulsa Geological Society 1508
Middle Miocene Production in Inglewood Oil Field, Recently Discovered. By A. F. Woodward. Abstract 947
Midland, Texas, Insoluble Residue Study Group. Geological Note by Taylor Cole 318
Midway Fauna of Western Gulf Province, Analysis of. By Julia Gardner . . . 644
———, Upper, of Louisiana, Correlation of. By R. J. LeBlanc. Abstract . . 941
Midway Group in Louisiana, Fossiliferous Localities of. Geological Note by Rufus J. LeBlanc and John O. Barry 734
Midway Microfauna of Northwestern Louisiana. Geological Note by Grover Murray, Jr. 738
Midway Stratigraphy of Sabine Uplift. By Grover Murray, Jr. Abstract . . . 941
Midway-Wilcox Deltaic Mass. By H. N. Fisk. Abstract 941
Migration of Oil, Cementing Materials in Sandstones and Their Influence on. By W. A. Waldschmidt 1839
——— from Arbuckle Limestone into Chattanooga Shale in Chetopa Oil Pool, Labette County, Kansas. Geological Note by G. E. Abernathy 1934
Migration and Accumulation of Petroleum, Report of Committee on. By F. M. Van Tuyl and Ben H. Parker. The Association Round Table 973
Miller, Robert H. Relationship between Some Types of Gravity Anomalies and Structure. Abstract 2097

Miller, W. J. Introduction to Physical Geology. Review by Herschel L. Driver . 2212
Milner, H. C. Sedimentary Petrography. Review by W. H. Twenhofel . . . 169
Mineral Economists Needed by the Government 1432
Mineral Resources of Bolivia. By Friedrich Ahlfeld and Jorges Muñoz Reyes. Review by John L. Rich 333
Minutes, Twenty-Sixth Annual Business Meeting, Rice Hotel, Houston, Texas, April 2–4, 1941. By Edgar W. Owen. The Association Round Table . . . 951
Miocene, Middle, Production in Inglewood Oil Field, Recently Discovered. By A. F. Woodward. Abstract 947
——— of Caliente Range and Environs, California. By J. E. Eaton, U. S. Grant, and H. B. Allen 193
Miocene Fishes in Well Cores from Torrance in Southern California. Geological Note by Lore David 319
Mississippi, Developments in, in 1940. By Urban B. Hughes 1016
———, Developments in, in 1940. By Urban B. Hughes. Abstract 928
———, Newman Salt Dome, Warren County. Geological Note by Joseph Neely 424
———, Notes on Geology of. By Tom McGlothlin. Abstract 929
———, Pickens Pool, Yazoo County. By Clarence E. Brehm. Abstract . . . 931
———, Tatum Salt Dome, Lamar County. Geological Note by Cecil L. Morgan 424
———, Upper Cretaceous Deposits in. By Lloyd William Stephenson and Watson Hiner Monroe. Review by Henry N. Toler 1601
Mississippi Geological Society. Possible Future Oil Provinces of Southeastern United States 1575
Mississippi Geological Society Fourth Annual Field Trip, December 6–8, 1940. By D. C. Harrell. The Association Round Table 181
Mississippian, Lower, in Western Michigan, Study of Sedimentation and Stratigraphy of. By Lucille Hale 713
Mississippian and Devonian Inliers of Southwestern Pennsylvania. Geological Note by Wilson M. Laird 161
Mississippian Formations of Sacramento Mountains, New Mexico. By L. R. Laudon and A. L. Bowsher 2107
———. Abstract 935
Mississippian Rocks, Subsurface, of Kansas. By Wallace Lee. Review by Hugh McClellan 1410
Missouri, Effective Porosity of Gas Fields in Jackson County, Geological Note by Glenn G. Bartle 1405
———. Abstract 947
———, Traverse of Upper Des Moines and Lower Missouri Series from Jackson County, to Appanoose County, Iowa. By L. M. Cline 23
Mistler, Alvin J., and Rhoades, Roger. Post-Appalachian Faulting in Western Kentucky 2046
Models, Oil-Field, of Shreveport Geological Society. Geological Note by C. E. Dobbin 1567
Monroe, Watson Hiner, and Stephenson, Lloyd William. Upper Cretaceous Deposits in Mississippi. Review by Henry N. Toler 1601
Moore, Raymond C. Ground-Water Resources of Kansas. Review by Hugh McClellan 1412
Morgan, Cecil L. Tatum Salt Dome, Lamar County, Mississippi. Geological Note 424
Mull, J. A. Stream Channels Applied to Arbuckle of Central Kansas Uplift. Abstract 946
Muller, Siemon Wm., and Schenck, Hubert G. Review of On Carboniferous Foraminifera of the Samara Bend, by D. Rauser-Černoussova, G. Beljaev, and E. Reitlinger 1943
———. The Standard of the Cretaceous System. Abstract 2094
Murray, Grover, Jr., Midway Microfauna of Northwestern Louisiana. Geological Note 738
———. Midway Stratigraphy of Sabine Uplift. Abstract 941
Myers, Thurman H. Memorial by M. G. Gulley 347

National Defense, Natural Gas with Regard to Its Place in. By N. C. McGowen 1291
National Defense Program, Petroleum Geologists in. By L. C. Snider . . . 1203

———. Abstract 935
National Oil Scouts and Landmen's Association. Oil and Gas Field Development in United States, 1940. Review by Joseph L. Borden 1942
National Research Council, 1940–1941, Report of Representative on Division of Geology and Geography of. By A. I. Levorsen. The Association Round Table 977
National Service Committee. By Ed. W. Owen. The Association Round Table . 1189
Natural Gas in Brantford Area, Ontario. By J. F. Caley. Review by Charles S. Evans 1950
——— with Regard to Its Place in National Defense. By N. C. McGowen . . 1291
Navarro Group of Texas, Summary of Faunal Studies of. By Lloyd William Stephenson 637
Nederlands East Indies, Small Foraminifera from the Late Tertiary of. By L. W. LeRoy. Review by M. C. Israelsky 761
Neely, Joseph. Newman Salt Dome, Warren County, Mississippi. Geological Note 424
Nettleton, L. L. Geophysical Prospecting for Oil. Review by John L. Ferguson . 328
Neumann, L. M., *et al.* Relationship of Crude Oils and Stratigraphy in Parts of Oklahoma and Kansas. Research Notes 1801
New Developments in North and West Central Texas, 1940. By H. F. Smiley. Abstract 940
———. By North Texas Geological Society 1064
New Methods of Electing Officers, Report of Special Committee to Recommend. The Association Round Table 965
New Mexico, Lateral Gradation in Seven Rivers Formation, Rocky Arroyo, Eddy County. By Robert L. Bates. Abstract 935
———, Mississippian Formations of Sacramento Mountains. By L. R. Laudon and A. L. Bowsher 2107
———. Abstract 935
———, New Source for Sodium Sulphate in. By Walter B. Lang 152
———, Southeastern, and West Texas, Developments in, during 1940. By Taylor Cole, Robert I. Dickey, and Edgar Kraus 1044
———, Southeastern, and West Texas, Developments in. By Taylor Cole, Robert I. Dickey, and Edgar Kraus. Abstract 933
———, Southeastern, and West Texas, Tansill Formation. By Ronald K. K. DeFord and George D. Riggs 713
New Mexico and West Texas, Position of San Andres Group. By Frank E. Lewis 73
New Source for Sodium Sulphate in New Mexico. By Walter B. Lang 152
New Zealand, Divisions of the Tertiary of. By H. J. Finlay and J. Marwick. Review by Hubert G. Schenck 763
———, Divisions of Upper Cretaceous and Tertiary in. By H. J. Finlay and J. Marwick. Review by Burton Wallace Collins 1813
Newfoundland. By Helgi Johnson. Possible Future Oil Provinces of Eastern Canada 1558
Newfoundland Geological Survey, Geological Survey of Canada, and Quebec Bureau of Mines. Possible Future Oil Provinces of Eastern Canada . 1539, 2194
Newman Salt Dome, Warren County, Mississippi. Geological Note by Joseph Neely 424
Niceville, Okaloosa County, Florida, Micropaleontology and Stratigraphy of a Deep Well at. By R. Hendee Smith 263
Niobrara and Benton in Foothills of Northern Colorado, Microfaunas of. By W. C. Toepelman. Abstract 940
Nomenclature, Stratigraphic. Discussion by Hubert G. Schenck *et al.*, Hollis D. Hedberg, C. W. Tomlinson, J. E. Eaton, and R. T. White 2195
Non-Marine Origin of Petroleum in North Shensi, and the Cretaceous of Szechuan, China. Geological Note by C. H. Pan 2058
North and West Central Texas, New Developments in, 1940. By H. F. Smiley. Abstract 940
———. By North Texas Geological Society 1064
North Central and Northeastern Oklahoma and Southeastern Kansas, Occurrence of Oil and Gas in Pennsylvanian Sands in. By Luther E. Kennedy. Abstract 945

North Cowden Field, Ector County, Texas. By Sam C. Giesey and Frank F. Fulk . . . 593
North Mid-Continent, Developments in, in 1940. By Edward A. Koester . . 1103
———. Abstract . . . 945
North Mid-Continent Region, Abstracts of Papers on. The Association Round Table . . . 945
North Shensi and the Cretaceous of Szechuan, China, Non-Marine Origin of Petroleum in. Geological Note by C. H. Pan . . . 2058
North Texas Geological Society. New Developments in North and West-Central Texas, 1940 . . . 1064
Northern Cumberland Plateau, Oil and Gas Possibilities in. By Kendall E. Born. Abstract . . . 944
Northern Louisiana and Southern Arkansas, Developments in, during 1940. By Joseph Purzer and Warren B. Weeks . . . 1024
Northern Mid-Continent States, Possible Future Oil Provinces of. By Tulsa Geological Society . . . 1508
Northwest Extension of Inglewood Field. By Robin Willis. Abstract . . . 2097
Northwestern Louisiana, Midway Microfauna of. Geological Note by Grover Murray, Jr. . . . 738
Nueces and San Patricio Counties, Texas, Oligocene Stratigraphy of East White Point Field. By Phil F. Martyn and Charles H. Sample . . . 1967

Oak Canyon Oil Field, Geological Notes on. By Wayne Loel, R. W. Clark, and Paul P. Goudkoff. Abstract . . . 2096
Oakes, Malcolm C. Memorial of Robert W. Sawyer . . . 1610
Oborne, Harry. Paleozoic Correlations from Southern Rocky Mountain Front Range to Oklahoma-Texas Panhandle. Abstract . . . 939
Observations, Laboratory and Field, of Effect of Acidizing Oil Reservoirs Composed of Sands. By P. E. Fitzgerald and Ray L. Austin . . . 850
——— on the Evolution of the Pacific Ocean. By Alex. L. du Toit. Review by Victor Oppenheim . . . 1811
Occurrence of Oil and Gas in Pennsylvanian Sands in North Central and Northeastern Oklahoma and Southeastern Kansas. By Luther E. Kennedy. Abstract . . . 945
Officers, New Method of Electing, Report of Special Committee. The Association Round Table . . . 965
———, Newly Elected, of Pacific Section of Association . . . 2094
——— of the Association, Past and Present. The Association Round Table . . . 545
———, Report of Special Committee to Recommend New Method of Electing. The Association Round Table . . . 965
Oil, Cementing Materials in Sandstone and Their Influence on Migration of. By W. A. Waldschmidt . . . 1839
———, Geophysical Prospecting for. By L. L. Nettleton. Review by John L. Ferguson . . . 328
——— in International Relations. By Walter H. Voskuil . . . 353
———, Origin of. By A. I. Levorsen. Research Notes . . . 2086
Oil Accumulation and Marine Sedimentation on Gulf Coast. By Dorothy A. Jung and Doris S. Malkin. Abstract . . . 930
Oil Accumulation and Marine Sedimentation on Gulf Coast. I. Progressive Marine Overlap. By Doris S. Malkin and Dorothy A. Jung . . . 2010
Oil and Gas from Sands, Recoverable, Estimation by Volumetric Methods. By John F. Dodge, Howard C. Pyle, and Everett G. Trostel . . . 1302
——— in Pennsylvanian Sands in North Central and Northeastern Oklahoma and Southeastern Kansas, Occurrence of. By Luther E. Kennedy. Abstract 945
Oil and Gas Development in Eastern Interior Basin in 1940. By Alfred H. Bell. Abstract . . . 942
Oil and Gas Developments in Michigan in 1940. By R. P. Grant . . . 1125
———. Abstract . . . 944
Oil and Gas Field Development in United States, 1940. By National Oil Scouts and Landmen's Association. Review by Joseph L. Borden . . . 1942
Oil and Gas Fields, Major Tectonic Provinces of Southern Oklahoma and Their Relation to. By E. A. Paschal . . . 1

Oil and Gas Possibilities in Northern Cumberland Plateau. By Kendall E. Born. Abstract . . . 944
Oil and Gas Stratigraphic Reservoirs in University Oil Field, East Baton Rouge Parish, Louisiana. By Michel T. Halbouty. Abstract . . . 930
Oil-Field Models of Shreveport Geological Society. Geological Note by C. E. Dobbin . . . 1587
Oil Fields—before Discovery and after Development. By James C. Kimble. Abstract . . . 2096
Oil Industry, Fifth Dimension in. By J. Edgar Pew . . . 1283
Oil Provinces, Possible Future, in Alaska. By Philip S. Smith . . . 1440
———, Possible Future, in Eastern United States. By Appalachian Geological Society . . . 1563
———, Possible Future, in Pacific Coast States. By Pacific Section of American Association of Petroleum Geologists . . . 1457
———, Possible Future, in Rocky Mountain Region. By Rocky Mountain Association of Petroleum Geologists . . . 1469
———, Possible Future, in Western Canada. By Alberta Society of Petroleum Geologists . . . 1447
———, Possible Future, of Eastern Canada. By Geological Survey of Canada, Quebec Bureau of Mines, and Newfoundland Geological Survey . . . 1539, 2194
———, Possible Future, of Northern Mid-Continent States. By Tulsa Geological Society . . . 1508
———, Possible Future, of Southeastern United States. By Mississippi Geological Society . . . 1575
———, Possible Future, of the United States and Canada. Foreword. By A. I. Levorsen . . . 1433
———, Possible Future, of West Texas. By West Texas Geological Society . . . 1527
Oil Reserves, This Matter of Estimating. Geological Note by Frederic H. Lahee 164
Oil Reservoirs Composed of Sands, Laboratory and Field Observations of the Effect of Acidizing. By P. E. Fitzgerald, F. R. James, and Ray L. Austin . 850
———. Abstract . . . 937
Okaloosa County, Florida, Micropaleontology and Stratigraphy of a Deep Well at Niceville. By R. Hendee Smith . . . 263
Oklahoma, Developments in, during 1940. By E. F. Shea . . . 1090
———, Memorial Shale of Pennsylvanian Age in. Geological Note by Robert H. Dott . . . 1591
———, North Central and Northeastern, and Southeastern Kansas, Occurrence of Oil and Gas in Pennsylvanian Sands in. By Luther E. Kennedy. Abstract . . . 945
———, Pre-Cambrian Zeolite-Opal Sediments in Wichita Mountains. By C. A. Merritt and W. E. Ham . . . 287
———, Significance of Initial Daily Production of Wells in Burbank and South Burbank Oil Fields. Geological Note by N. Wood Bass . . . 1175
———, Simpson Group of Arbuckle and Wichita Mountains. By Charles E. Decker . . . 650
———, Southern, Major Tectonic Provinces of, and Their Relation to Oil and Gas Fields. By E. A. Paschal . . . 1
Oklahoma and Kansas, Relationship of Crude Oils and Stratigraphy in Parts of. By L. M. Neumann *et al.* Research Notes . . . 1801
Oklahoma City Geological Society Field Trip, May 30, 31, June 1 . . . 996
Oklahoma City Oil Pool, Exercise on Amount of Source Bed Required to Furnish. By Roy L. Ginter . . . 1706
Oklahoma-Texas Panhandle, Paleozoic Correlations from Southern Rocky Mountain Front Range to. By Harry Oborne. Abstract . . . 939
Oligocene Stratigraphy of East White Point Field, San Patricio and Nueces Counties, Texas. By Phil F. Martyn and Charles H. Sample . . . 1967
———. Abstract . . . 932
Olla Field, La Salle Parish, Louisiana. Geological Note by S. A. Packard and H. R. Kamb . . . 747
Olson, Walter S. Seismic Velocity Variations in San Joaquin Valley, California 1343
On Carboniferous Foraminifera of the Samara Bend. By D. Rauser-Cernoussova, G. Beljaev, and E. Reitlinger. Review by Siemon Wm. Muller and Hubert G. Schenck . . . 1943

Ontario, Natural Gas in Brantford Area. By J. F. Caley. Review by Charles S. Evans 1950
Opal-Zeolite Sediments, Pre-Cambrian, in Wichita Mountains, Oklahoma. By C. A. Merritt and W. E. Ham 287
Oppenheim, Victor. Review of Observations on the Evolution of the Pacific Ocean, by Alex. L. du Toit 1811
Organic Matter, Relation of, to Color of Sedimentary Rocks. By H. Whitman Patnode 1921
Origin, Non-Marine, of Petroleum in North Shensi, and the Cretaceous of Szechuan, China. Geological Note by C. H. Pan 2058
——— of Oil. By A. I. Levorsen. Research Notes 2086
Osage Group, Subsurface Strata between Base of, and Top of Devonian Limestone in Illinois. By L. E. Workman and I. T. Sehwade. Abstract . . . 943
Osborn, W. M. Stratigraphic Trap of Slaughter Field of West Texas. Abstract . 934
Overlap, Progressive Marine. Marine Sedimentation and Oil Accumulation on Gulf Coast. I. By Doris S. Malkin and Dorothy A. Jung 2010
Owen, Edgar W. Minutes, Twenty-Sixth Annual Business Meeting, Rice Hotel, Houston, Texas, April 2–4, 1941. The Association Round Table 951
———. National Service Committee. The Association Round Table 1189
———. Report (Minutes) of Business Committee. The Association Round Table 964
———, Report of Secretary-Treasurer. The Association Round Table . . . 953
Owen, Edgar W., Rôle of Surface Geology in Petroleum Exploration. Abstract 936

Pacific Coast States, Possible Future Oil Provinces in. By Pacific Section of American Association of Petroleum Geologists 1457
Pacific Ocean, Observations on the Evolution of. By Alex. L. du Toit. Review by Victor Oppenheim 1811
Pacific Section of American Association of Petroleum Geologists. Possible Future Oil Provinces in Pacific Coast States 1457
———, of Association, Newly Elected Officers 2094
Pacific Section Annual Meeting, Los Angeles, October 16–17. Announcement. The Association Round Table 1189
Pacific Section Eighteenth Annual Meeting, Los Angeles, October 16–17, 1941. Abstracts. The Association Round Table 2093
Packard, S. A., and Kamb, H. R. Olla Field, La Salle Parish, Louisiana. Geological Note 747
Page Field, Schleicher County, Texas. By Roscoe Simpson 630
Paleogeography and Correlation: Upper Paleozoic of Western Australia. By Curt Teichert. 371, 1809
Paleontology and Mineralogy, Division of, Titles of Papers on Program of. The Association Round Table 948
Paleozoic, Upper, of Western Australia: Correlation and Paleogeography, By Curt Teichert 371, 1809
Paleozoic and Recent Branching Hexactinellida; The Titusvilliidae. By Kenneth E. Caster. Review by W. A. Ver Wiebe 2082
Paleozoic Correlations from Southern Rocky Mountain Front Range to Oklahoma-Texas Panhandle. By Harry Oborne. Abstract 939
Paleozoic Formations of the Japanese Islands. By Hisakatsu Yabe. Review by Hubert G. Schenck 767
Pan, C. H. Non-Marine Origin of Petroleum in North Shensi and the Cretaceous of Szechuan, China. Geological Note 2058
Papers on Program of Division of Paleontology and Mineralogy. The Association Round Table 948
Papers on Program of Society of Exploration Geophysicists, Titles of. The Association Round Table 949
Park County, Wyoming, Heart Mountain and South Fork Thrusts. By William G. Pierce 2021
Parker, Ben H., and Van Tuyl, F. M. Report of Committee on Migration and Accumulation of Petroleum. The Association Round Table 973
Paschal, E. A. Major Tectonic Provinces of Southern Oklahoma and Their Relation to Oil and Gas Fields 1

———, Memorial of Charles Theodore Casebeer 1831
Past and Present Officers of the Association. The Association Round Table . . 545
Pennsylvania, Graywackes and the Petrology of Bradford Oil Field. Discussion by Paul D. Krynine 2071
———, Southwestern, Devonian and Mississippian Inliers of. Geological Note by Wilson M. Laird 161
Pennsylvanian Age, Memorial Shale of, in Oklahoma. Geological Note by Robert H. Dott 1591
Pennsylvanian Sands in North Central and Northeastern Oklahoma and Southeastern Kansas, Occurrence of Oil and Gas in. By Luther E. Kennedy. Abstract 945
Perforators, Gun, Formation Samples from. Geological Note by J. T. Richards 752
Permian Correlation Meeting, Centennial, Wyoming, September 2, 1940. Geological Note by Ronald K. DeFord 429
Permian Crude Oils, Progress Report on Microscopic Examination of. By W. A. Waldschmidt. Abstract 934
Permian Volume, Progress on. The Association Round Table 972
Petrographic Studies of Sandstone Cores from Rocky Mountain Structures, Results of. By W. A. Waldschmidt. Abstract 939
Petrography, Sedimentary. By H. C. Milner. Review by W. H. Twenhofel . . 169
Petroleum in North Shensi, and the Cretaceous of Szechuan, China, Non-Marine Origin of. Geological Note by C. H. Pan 2058
Petroleum and Genesis of the Third Bradford Sand. By Paul D. Krynine. Review by Parke A. Dickey 1413
Petroleum and the War. By Robert E. Wilson 1264
Petroleum Development and Technology, 1941. By A. I. M. E. Petroleum Division. Review by G. S. Dillé 1950
Petroleum Division, A. I. M. E. Petroleum Development and Technology, 1941. Review by G. S. Dillé. 1950
Petroleum Engineering, Petroleum Geology, and Economic Geology, Radioactivity Well Logs, Their Use and Application in Fields of. By. J. C. Barcklow. Abstract 938
Petroleum Exploration, Rôle of Surface Geology in. By Edgar W. Owen Abstract 936
Petroleum Geologist, The, and the Securities and Exchange Commission. By Sumner T. Pike 1297
Petroleum Geologists in the National Defense Program. By L. C. Snider. . . 1203
———. Abstract 935
Petroleum Geology, Economic Geology, and Petroleum Engineering, Radioactivity Well Logs, Their Use and Application in Fields of. By J. C. Barcklow. Abstract 938
———, Where Should Young Graduates in, Acquire Field Experience? Discussion by Ralph B. Ross 1180
Petroleum Industry, Elements of. By Many Authors. Review by Wallace E. Pratt 904
Petroleum Technology, Annual Reviews of. By the Institute of Petroleum. Review by J. E. Brantly 327
Petrology of Bradford Oil Field, Pennsylvania, and Graywackes. Discussion by Paul D. Krynine 2071
Pew, J. Edgar. Fifth Dimension in the Oil Industry 1283
Photogeology. Geological Note by Henry Carter Rea 1796
Physical Geology, Introduction to. By W. J. Miller. Review by Herschel L. Driver 2212
Pickens Pool, Yazoo County, Mississippi. By Clarence E. Brehm. Abstract . . 931
Pierce, William G. Heart Mountain and South Fork Thrusts, Park County, Wyoming 2021
Pike, Sumner T. The Petroleum Geologist and the Securities and Exchange Commission 1297
Poirier, O. A., and Thiel, G. A. Deposition of Free Oil by Sediments Settling in Sea Water 2170
Pool, Frank M. Houston Geological Society Student Award. The Association Round Table 1607
Popenoe, W. P. Cretaceous—East Side Sacramento Valley. Abstract . . . 2095

Porosity, Effective, of Gas Fields in Jackson County, Missouri. By Glenn G. Bartle. Abstract 947
———. Geological Note by Glenn G. Bartle 1405
Porter II, William W., and Goudkoff, Paul P. Age of Shale in Amoura-Uscari Area, Costa Rica. Abstract 947
Porto Rico, Tertiary Foraminifera of. By J. J. Galloway and Caroline E. Heminway. Review by Alva C. Ellisor 1810
Position of San Andres Group, West Texas and New Mexico. By Frank E. Lewis 73
Possible Future Oil Provinces in Alaska. By Philip S. Smith 1440
———, in Eastern United States. By Appalachian Geological Society . . . 1563
———, in Pacific Coast States. By Pacific Section of American Association of Petroleum Geologists 1457
———, in Rocky Mountain Region. By Rocky Mountain Association of Petroleum Geologists 1469
——— in Western Canada. By Alberta Society of Petroleum Geologists . . . 1447
——— of Eastern Canada. By Geological Survey of Canada, Quebec Bureau of Mines, and Newfoundland Geological Survey 1539, 2194
——— of Northern Mid-Continent States. By Tulsa Geological Society . . . 1508
——— of Southeastern United States. By Mississippi Geological Society . . 1575
——— of the United States and Canada. Foreword. By A. I. Levorsen. . . 1433
——— of West Texas. By West Texas Geological Society 1527
Post-Appalachian Faulting in Western Kentucky. By Roger Rhoades and Alvin J. Mistler 2046
Pratley, Fred. Memorial of Henry Hart Pratley 1962
Pratley, Henry Hart. Memorial by Fred Pratley 1962
Pratt, Wallace E. Review of Elements of the Petroleum Industry, by Many Authors 904
Pre-Cambrian Zeolite-Opal Sediments in Wichita Mountains, Oklahoma. By C. A. Merritt and W. E. Ham 287
Pre-Cretaceous Sediments in Cordillera Oriental of Colombia. By Parke A. Dickey 1789
Pre-Miocene Stratigraphy of Bakersfield Area, California. By Alex Clark. Abstract 947
President, Report of. By L. C. Snider. The Association Round Table 952
Presidential Addresses at Twenty-Sixth Annual Meeting. American Association of Petroleum Geologists. The Association Round Table 935
Prettyman, Thomas Mann. Memorial by C. L. Renaud 346
Price, Paul H., and Headlee, A. J. W. Geochemistry of Natural Gas in Appalachian Province. Abstract 942
Problems, Some, of Appalachian Structure. By R. E. Sherrill 416
Proceedings of the Florida Academy of Sciences for 1939. Review by Robert B. Campbell 168
Production, Initial, Relation of, to Ultimate Production of Wells Completed in Smithwick (Gray) Limestone, Breckenridge Field, Stephens County, Texas. Geological Note by David Donoghue 1589
———, Initial Daily, of Wells in Burbank and South Burbank Oil Fields, Oklahoma, Significance of. Geological Note by N. Wood Bass 1175
———, Ultimate, of Wells Completed in Smithwick (Gray) Limestone. Breckenridge Field, Stephens County, Texas, Relation of Initial Production to. Geological Note by David Donoghue 1589
Progress of Stratigraphic Studies in California. By E. W. Galliher and E. R. Atwill. Abstract 946
Progress Report on Microscopic Examination of Permian Crude Oils. By W. A. Waldschmidt. Abstract 934
——— on Radioactivity of Petroleum and Natural Gas. By Clark Goodman and W. L. Whitehead. The Association Round Table 975
Progressive Marine Overlap. Marine Sedimentation and Oil Accumulation on Gulf Coast. I. By Doris S. Malkin and Dorothy A. Jung 2010
Prospecting for Oil, Geophysical. By L. L. Nettleton. Review by John L. Ferguson 328
Publication, Report of Committee for. By Robert E. Rettger. The Association Round Table 979
Publications, Report on. By Ronald K. DeFord. The Association Round Table 972

Purzer, Joseph, and Weeks, Warren B. Developments in Southern Arkansas and Northern Louisiana during 1940 1024
———. Abstract 943
Pyle, Howard C., Dodge, John F., and Trostel, Everett G. Estimation by Volumetric Methods of Recoverable Oil and Gas from Sands. 1302

Quebec. By I. W. Jones. Possible Future Oil Provinces of Eastern Canada . . 1555
Quebec Bureau of Mines, Geological Survey of Canada, and Newfoundland Geological Survey. Possible Future Oil Provinces of Eastern Canada . 1539, 2194

Radioactivity of Petroleum and Natural Gas, Progress Report on. By Clark Goodman and W. L. Whitehead. The Association Round Table 975
———, Well Logging by. By William L. Russell 1768
———. Discussion by William L. Russell 2211
Radioactivity Logging, Applications of. By William L. Russell. Abstract. . . 938
Radioactivity Well Logging through Casing. By Lowell C. Beers. Abstract. . 2098
Radioactivity Well Logs, Their Use and Application in Fields of Petroleum Geology, Economic Geology, and Petroleum Engineering. By J. C. Barcklow. Abstract 938
Rankin, Robert Estes. West Texas Geological Society Student Merit Award. The Association Round Table 1188
Rauser-Černoussova, D., Beljaev, G., and Reitlinger, E. On Carboniferous Foraminifera of the Samara Bend. Review by Siemon Wm. Muller and Hubert G. Schenck 1943
Rea, Henry Carter. Applied Sedimentology. Geological Note 899
———. Photogeology. Geological Note 1796
Recent and Paleozoic Branching Hexactinellida; The Titusvilliidae. By Kenneth E. Caster. Review by W. A. Ver Wiebe 2082
Recent Publications 174, 334, 440, 768, 906, 1183, 1423, 1602, 1817, 1951, 2083, 2212
Recently Discovered Middle Miocene Production in Inglewood Oil Field. By A. F. Woodward. Abstract 947
Recoverable Oil and Gas from Sands, Estimation by Volumetric Methods. By John F. Dodge, Howard C. Pyle, and Everett G. Trostel 1302
Refugio County, Texas, La Rosa Field. By Barney Fisher 300
Regional Stratigraphy of Mid-Continent. By Robert H. Dott 1619
Reinhart, Philip W. Cretaceous—West Side Sacramento Valley North of Willows. Abstract 2095
Reitlinger, E., Rauser-Černoussova, D., and Beljaev, G. On Carboniferous Foraminifera of the Samara Bend. Review by Siemon Wm. Muller and Hubert G. Schenck 1943
Relation of Initial Production to Ultimate Production of Wells Completed in Smithwick (Gray) Limestone, Breckenridge Field, Stephens County, Texas. Geological Note by David Donoghue 1589
——— of Organic Matter to Color of Sedimentary Rocks. By H. Whitman Patnode 1921
Relationship between Some Types of Gravity Anomalies and Structure. By Robert H. Miller. Abstract 2097
——— of Crude Oils and Stratigraphy in Parts of Oklahoma and Kansas. By L. M. Neumann *et al.* Research Notes 1801
Remarks at Opening of Twenty-Sixth Annual Meeting. By George S. Buchanan 1201
——— at the Fifty-Third Annual Meeting of the Geological Society of America. By L. C. Snider. The Association Round Table 916
Renaud, C. L. Memorial of Thomas Mann Prettyman 346
Report (Minutes) of Business Committee. By Edgar W. Owen. The Association Round Table 964
——— of Chairman of Research Committee. By A. I. Levorsen. The Association Round Table 972
——— of Chairman of Resolutions Committee. By A. R. Denison. The Association Round Table 980
——— of Committee for Publication. By Robert E. Rettger. The Association Round Table 979
——— of Committee on Geologic Names and Correlations. By John G. Bartram. The Association Round Table 977

——— of Committee on Migration and Accumulation of Petroleum. By F. M. Van Tuyl and Ben H. Parker. The Association Round Table 973
——— of Editor. By W. A. Ver Wiebe. The Association Round Table . . . 961
——— of President. By L. C. Snider. The Association Round Table . . . 952
——— of Representative on Division of Geology and Geography of National Research Council, 1940–1941. By A. I. Levorsen. The Association Round Table 977
——— of Secretary-Treasurer. By Edgar W. Owen. The Association Round Table 953
——— of Special Committee on College Curricula. The Association Round Table 969
——— of Special Committee to Recommend New Method of Electing Officers. The Association Round Table 965
——— on Publications. By Ronald K. DeFord. The Association Round Table 972
Representative on Division of Geology and Geography of National Research Council, 1940–1941, Report of. By A. I. Levorsen. The Association Round Table 977
Research Committee, Report of Chairman. By A. I. Levorsen. The Association Round Table 972
Research Committee Conferences. By A. I. Levorsen. Research Notes . . . 337
Research Dinner—Round Table Discussion. By A. I. Levorsen. Research Notes 177
Research Notes 177, 337, 910, 1600, 1801, 2086
Reservoirs, Oil, Composed of Sands, Laboratory and Field Observations of the Effect of Acidizing. By P. E. Fitzgerald, F. R. James, and Ray L. Austin. . 850
Resolutions Committee, Report of Chairman. By A. R. Denison. The Association Round Table 980
Resources, Ground-Water, of Kansas. By Raymond C. Moore. Review by Hugh McClellan 1412
Results of Petrographic Studies of Sandstone Cores from Rocky Mountain Structures. By W. A. Waldschmidt. Abstract 939
Résumé on Sedimentation in Gulf Coast Region of Texas and Louisiana. By L. W. Storm. Abstract 936
Rettger, Robert E. Report of Committee for Publication. The Association Round Table 979
Review of Developments in 1940, Gulf Coast of Upper Texas and Louisiana. By O. L. Brace 1004
Reviews and New Publications . . . . . 168, 327, 440, 760, 902, 1181, ... 1410, 1601, 1810, 1940, 2075, 2212
Reyes, Jorge Muñoz, and Ahlfeld, Friedrich. Die Bodenschätze Boliviens (The Mineral Resources of Bolivia). Review by John L. Rich 333
Rhoades, Roger, and Mistler, Alvin J. Post-Appalachian Faulting in Western Kentucky 2046
Rhythm of the Ages. By A. W. Grabau. Review by Edwin Kirk 1421
Rich, John L. Review of Die Bodenschätze Boliviens (The Mineral Resources of Bolivia), by Friedrich Ahlfeld and Jorge Muñoz Reyes 333
Richards, J. T. Formation Samples from Gun Perforators. Geological Note . . 752
———. Walter George Woolnough, Honorary Member. The Association Round Table 1954
Richardson, Carl B. Comparative Study of Origin and Distribution of Gulf Coast Tertiary Sediments. Abstract. 929
Richardson, G. B. Memorial of Marius Robinson Campbell 546
Richardson, H. T., and Ferrando, Al. Barataria Field, Jefferson Parish, Louisiana. Geological Note 322
Riggs, George D., and DeFord, Ronald K. Tansill Formation, West Texas and Southeastern New Mexico 1713
Rio Grande and Brazos River, Late Cenozoic Deposits of Texas Coastal Plain between. By A. W. Weeks. Abstract 932
Riter, Samuel W. Memorial by D. G. Emrick 2100
Roach, C. B. Subsurface Study of Jennings Dome, Acadia Parish, Louisiana. Abstract 929
Rocky Arroyo, Eddy County, New Mexico, Lateral Gradation in Seven Rivers Formation. By Robert L. Bates. Abstract 935
Rocky Mountain and Colorado Region, Guidebooks on 2092
Rocky Mountain Area, Abstracts of Papers on. The Association Round Table. 938

Rocky Mountain Association of Petroleum Geologists. Possible Future Oil Provinces in Rocky Mountain Region 1469
Rocky Mountain District, Developments in, in 1940. By C. E. Dobbin. . . . 1149
Rocky Mountain Front Range, Southern, to Oklahoma-Texas Panhandle, Paleozoic Correlations from. By Harry Oborne. Abstract 939
Rocky Mountain Region, Developments in, in 1940. By C. E. Dobbin. Abstract 938
———, Possible Future Oil Provinces in. By Rocky Mountain Association of Petroleum Geologists 1469
Rocky Mountain Structures, Results of Petrographic Studies of Sandstone Cores from. By. W. A. Waldschmidt. Abstract 939
Rôle of Surface Geology in Petroleum Exploration. By Edgar W. Owen. Abstract 936
Ross, Ralph B. Where Should Young Graduates in Petroleum Geology Acquire Field Experience? Discussion 1180
Round Table Discussion—Research Dinner. By A. I. Levorsen. Research Notes 177
Round Table Discussions at Twenty-Sixth Annual Meeting, American Association of Petroleum Geologists. The Association Round Table. 976
Roy, Chalmer J., and Glockzin, Albert R. Tentative Correlation Chart of Gulf Coast. Geological Note 742
Rubey, William W. Review of Strength and Structure of the Earth, by R. A. Daly. 902
Russell, R. Dana. Future of Field Geology. Discussion 324
Russell, William L. Applications of Radioactivity Logging. Abstract 938
———. Well Logging by Radioactivity 1768
———. Discussion 2211
Russia, Classification of Artinskian Series in. By G. Marshall Kay 1396

Sabine Uplift, Midway Stratigraphy of. By Grover Murray, Jr. Abstract . . 941
Sacramento Mountains, New Mexico, Mississippian Formations of. By L. R. Laudon and A. L. Bowsher 2107
———. Abstract 935
Sacramento Valley, East Side—Cretaceous. By W. P. Popenoe. Abstract . . 2095
———, South of Willows, Glenn County, California, Upper Cretaceous Stratigraphy of West Side of. By James M. Kirby. Abstract 2095
———, West Side of, North of Willows—Cretaceous. By Philip W. Rinehart. Abstract 2095
Salt-Dome Cap Rocks, Gold, Silver, and Other Elements in. Geological Note by Marcus A. Hanna and Albert G. Wolf 750
Salts, Evaporite, in Green River Basin, Wyoming, Exploration for. Geological Note by R. G. Greene. 1799
Samara Bend, On Carboniferous Foraminifera of the. By D. Rauser-Cernoussova, G. Beljaev, and E. Reitlinger. Review by Siemon Wm. Muller and Hubert G. Schenck 1943
Sample, Charles H., and Martyn, Phil F. Oligocene Stratigraphy of East White Point Field, San Patricio and Nueces Counties, Texas. 1967
———. Abstract 932
Samples, Formation, from Gun Perforators. Geological Note by J. T. Richards 752
San Andres Group, West Texas and New Mexico, Position of. By Frank E. Lewis 73
San Joaquin Valley, California, Seismic Velocity Variations in. By Walter S. Olson 1343
———, Discussion of Part of Upper Cretaceous Along West Border of. By A. S. Huey and J. W. Daly. Abstract 2096
———, Southern, California. Stevens Sand. By Rollin Eckis. Abstract . . . 946
San Patricio and Nueces Counties, Texas, Oligocene Stratigraphy of East White Point Field. By Phil F. Martyn and Charles H. Sample 1967
Sandstone Cores from Rocky Mountain Structures, Results of Petrographic Studies of. By W. A. Waldschmidt. Abstract 939
Sandstones, Cementing Materials in, and Their Influence on Migration of Oil. By W. A. Waldschmidt 1839
Santa Lucia Range, Cretaceous of. By N. L. Taliaferro. Abstract 2095
Sawyer, Robert W. Memorial by Malcolm C. Oakes 1610
Schenck, Hubert G. Review of Paleozoic Formations of the Japanese Islands. by Hisakatsu Yabe 767

———. Review of The Divisions of the Tertiary of New Zealand, by H. J. Finlay and J. Marwick 763
Schenck, Hubert G., and Muller, Siemon Wm. Review of On Carboniferous Foraminifera of the Samara Bend, by D. Rauser-Černoussova, G. Beljaev, and E. Reitlinger 1943
———. The Standard of the Cretaceous System. Abstract 2094
Schenck, Hubert G., *et al.*, Hedberg, Hollis, D., Tomlinson, C. W., Eaton, J. E., and White, R. T. Stratigraphic Nomenclature. Discussion 2195
Schleicher County, Texas, Page Field. By Roscoe Simpson 630
Schneider, W. T. Geology of Wasson Field, Gaines and Yoakum Counties, Texas. Abstract 933
Science and Industry, Temperature, Its Measurement and Control in. A Symposium. Review by Roger C. Wells 1416
Scientific Societies, Meetings of, in December. The Association Round Table . 2217
Scobey, E. H., and Dana, P. L. Cross Section of Chester of Illinois Basin . . 871
Sea Water, Deposition of Free Oil by Sediments Settling in. By O. A. Poirier and G. A. Thiel 2170
Secretary-Treasurer, Report of. By Edgar W. Owen. The Association Round Table 953
Securities and Exchange Commission and the Petroleum Geologist. By Sumner T. Pike 1297
Sedimentary Cycles in Eocene of Texas Coastal Plain. By H. B. Stenzel. Abstract 933
Sedimentary Petrography. By H. C. Milner. Review by W. H. Twenhofel . . 169
Sedimentary Rocks, Relation of Organic Matter to Color of. By H. Whitman Patnode 1921
Sedimentation in Gulf Coast Region of Texas and Louisiana, Résumé on. By L. W. Storm. Abstract 936
———, Marine, and Oil Accumulation on Gulf Coast. By Dorothy A. Jung and Doris S. Malkin. Abstract 930
———, Marine, and Oil Accumulation on Gulf Coast. I. Progressive Marine Overlap. By Doris S. Malkin and Dorothy A. Jung 2010
Sedimentation and Stratigraphy of Lower Mississippian in Western Michigan, Study of. By Lucille Hale 713
Sedimentology, Applied. Geological Note by Henry Carter Rea 899
Sediments, Methods of Study. By W. H. Twenhofel and S. A. Tyler. Review by Marcus A. Hanna 1420
——— of Fresh-Water Lakes. By W. H. Twenhofel and V. E. McKelvey . . 826
———, Pre-Cretaceous, in Cordillera Oriental of Colombia. By Parke A. Dickey 1789
——— Settling in Sea Water, Deposition of Free Oil by. By O. A. Poirier and G. A. Thiel 2170
Sehwade, I. T., and Workman, L. E. Subsurface Strata between Base of Osage Group and Top of Devonian Limestone in Illinois. Abstract 943
Seismic Velocity Variations in San Joaquin Valley, California. By Walter S. Olson 1343
Seven Rivers Formation, Rocky Arroyo, Eddy County, New Mexico, Lateral Gradation in. By Robert L. Bates. Abstract 935
Shadowgraphic Contour Maps, Experiments with Lights, Shadows, and Contours, and Resulting. By Robert F. Imbt 2161
Shale, Memorial, of Pennsylvanian Age, in Oklahoma. Geological Note by Robert H. Dott 1591
Shale Formations, Antrim-Ellsworth-Coldwater, in Michigan. By Eleanor Tarbell 724
Shea, E. F. Developments in Oklahoma during 1940 1090
Shensi, North, Non-Marine Origin of Petroleum in, and the Cretaceous of Szechuan, China. Geological Note by C. H. Pan 2058
Shepard, Francis P., and Emery, K. O. Submarine Topography off the California Coast: Canyons and Tectonic Interpretation. Review by John L. Ferguson 1940
Sherman, R. W. Del Valle Oil Field, Los Angeles County, California. Abstract. 947
Sherrill, R. E. Some Problems of Appalachian Structure 416
Shipley Field, Ward County, Texas, Silurian Production. Geological Note by C. D. Cordry and M. E. Upson 425

Shoestring Sand Gas Fields of Michigan. By Max W. Ball, T. J. Weaver, and Douglas S. Ball. Abstract 942
Shreveport Geological Society, Oil-Field Models of. Geological Note by C. E. Dobbin 1587
Significance of Initial Daily Production of Wells in Burbank and South Burbank Oil Fields, Oklahoma. Geological Note by N. Wood Bass. 1175
Silurian Production, Shipley Field, Ward County, Texas. Geological Note by C. D. Cordry and M. E. Upson 425
Silver, Gold, and Other Elements in Salt-Dome Cap Rocks. Geological Note by Marcus A. Hanna and Albert G. Wolf 750
Simmons, Jesse Elmore. Memorial by E. W. Kimball 1610
Simonson, Russell R., and Krueger, Max L. Crocker Flat Infolded Landslide and Coarse Clastics in Temblor Range, California. Abstract 2097
Simpson, Roscoe. Page Field, Schleicher County, Texas 630
Simpson Group of Arbuckle and Wichita Mountains of Oklahoma. By Charles E. Decker 650
Singewald, Joseph T., Jr. Memorial of George Martin Hall 1828
Singleton, F. A. Tertiary Geology of Australia. Review by Burton Wallace Collins 1813
Slaughter Field of West Texas, Stratigraphic Trap of. By W. M. Osborn. Abstract 934
Small Foraminifera from Late Tertiary of the Nederlands East Indies. By L. W. LeRoy. Review by M. C. Israelsky 761
Smiley, H. F. New Developments in North and West Central Texas, 1940. Abstract 940
Smith, H. T. U. Improved Method of Handling Microfilm Copy. Geological Note. 2068
Smith, Philip S. Possible Future Oil Provinces in Alaska 1440
Smith, R. Hendee. Micropaleontology and Stratigraphy of a Deep Well at Niceville, Okaloosa County, Florida 263
Smithwick (Gray) Limestone, Relation of Initial Production to Ultimate Production of Wells Completed in, Breckenridge Field, Stephens County, Texas. Geological Note by David Donoghue 1589
Snider, L. C. Petroleum Geologists in the National Defense Program 1203
———. Abstract 935
———. Remarks at the Fifty-Third Annual Meeting of the Geological Society of America. The Association Round Table 916
———. Report of President. The Association Round Table 952
Society of Economic Paleontologists and Mineralogists Council. The Association Round Table 927
Society of Exploration Geophysicists, Executive Committee. The Association Round Table 927
Sodium Sulphate, New Source for, in New Mexico. By Walter B. Lang . . 152
Some Drilling-Time Logs and Their Uses. By Robin Willis. Abstract . . . 2097
Some Problems of Appalachian Structure. By R. E. Sherrill 416
Source, New, for Sodium Sulphate in New Mexico. By Walter B. Lang . . . 152
——— of Bulletin Papers. The Association Round Table 962
Source Bed Required to Furnish Oklahoma City Oil Pool, Exercise on Amount of. By Roy L. Ginter 1706
South Burbank and Burbank Oil Fields, Oklahoma, Significance of Initial Daily Production of Wells in. Geological Note by N. Wood Bass. 1175
South Cotton Lake Field, Chambers County, Texas. By Joseph M. Wilson . . 1898
———. Abstract 931
South Fork and Heart Mountain Thrusts, Park County, Wyoming. By William G. Pierce 2021
South Mid-Continent Region, Abstracts of Papers on. The Association Round Table 940
South Texas, Developments in, during 1940. By L. B. Herring 1037
———. Abstract 931
South Texas Area, Abstracts of Papers on. The Association Round Table . . 931
South Texas Geological Society Student Award. The Association Round Table. 1607
South Texas Section Thirteenth Annual Meeting, October 31, November 1–2. Announcement. At Home and Abroad 1966

Southeastern New Mexico and West Texas, Developments in, during 1940. By Taylor Cole, Robert I. Dickey, and Edgar Kraus 1044
———, Tansill Formation. By Ronald K. DeFord and George D. Riggs. . . 1713
Southeastern Turkey, Temperature Measurements in Three Wells in. Geological Note by Cevat Tasman 1937
Southeastern United States, Possible Future Oil Provinces of. By Mississippi Geological Society 1575
Southern Arkansas, Lower Cretaceous and Jurassic Formations of. By Ralph W. Imlay. Review by W. S. Adkins. 329
Southern Arkansas and Northern Louisiana, Developments in, during 1940. By Joseph Purzer and Warren B. Weeks 1024
Southern California, Miocene Fishes in Well Cores from Torrance. Geological Note by Lore David 319
Southern Oklahoma, Major Tectonic Provinces of, and Their Relation to Oil and Gas Fields. By E. A. Paschal 1
Southern Rocky Mountain Front Range to Oklahoma-Texas Panhandle. Paleozoic Correlations from. By Harry Oborne. Abstract 939
Southern San Joaquin Valley, California, Stevens Sand. By Rollin Eckis. Abstract 946
Southwestern Colorado, Correlation of Cross' La Plata Sandstone. By Marcus I. Goldman and Arthur C. Spencer 1745
Spencer, Arthur C., and Goldman, Marcus I. Correlation of Cross' La Plata Sandstone, Southwestern Colorado 1745
Standard of the Cretaceous System. By Siemon Wm. Muller and Hubert G. Schenck. Abstract 2094
Steinberger, C. R., and Kornfeld, M. M. Edna Gas Field, Jackson County, Texas 104
Stenzel, H. B. Sedimentary Cycles in Eocene of Texas Gulf Coastal Plain. Abstract 933
Stephens County, Texas, Relation of Initial Production to Ultimate Production of Wells Completed in Smithwick (Gray) Limestone, Breckenridge Field. Geological Note by David Donoghue 1589
Stephenson, Lloyd William. Summary of Faunal Studies of Navarro Group of Texas 637
Stephenson, Lloyd William, and Monroe, Watson Hiner. Upper Cretaceous Deposits in Mississippi. Review by Henry N. Toler 1601
Stevens Sand, Southern San Joaquin Valley, California. By Rollin Eckis. Abstract 946
Stock, Chester. Cretaceous Vertebrate Record of California. Abstract . . . 2094
Storm, L. W. Résumé on Sedimentation in Gulf Coast Region of Texas and Louisiana. Abstract 936
Stratigraphic Nomenclature. Discussion by Hubert G. Schenck *et al.*, Hollis D. Hedberg, C. W. Tomlinson, J. E. Eaton, and R. T. White 2195
Stratigraphic Reservoirs, Oil and Gas, in University Oil Field, East Baton Rouge Parish, Louisiana. By Michel T. Halbouty. Abstract 930
Stratigraphic Studies in California, Progress of. By E. W. Galliher and E. R. Atwill. Abstract 946
Stratigraphic Trap of Slaughter Field of West Texas. By W. M. Osborn. Abstract 934
Stratigraphy, Midway, of Sabine Uplift. By Grover Murray, Jr. Abstract . . 941
———, Oligocene, of East White Point Field, San Patricio and Nueces Counties, Texas. By Phil F. Martyn and Charles H. Sample 1967
———, Regional, of Mid-Continent. By Robert H. Dott 1619
———, Upper Cretaceous, of West Side of Sacramento Valley South of Willows, Glenn County, California. By James M. Kirby. Abstract 2095
Stratigraphy and Crude Oils, Relationship of, in Parts of Oklahoma and Kansas. By L. M. Neumann *et al.* Research Notes 1801
Stratigraphy and Micropaleontology of a Deep Well at Niceville, Okaloosa County, Florida. By R. Hendee Smith 263
Stratigraphy and Sedimentation of Lower Mississippian in Western Michigan, Study of. By Lucille Hale 713
Stream Channels Applied to Arbuckle of Central Kansas Uplift. By J. A. Mull. Abstract 946

Strength and Structure of the Earth. By Reginald Aldworth Daly. Review by Roland F. Beers . . . 1181
———. Review by William W. Rubey . . . 902
Structure, Appalachian, Some Problems of. By R. E. Sherrill . . . 416
———, Relationship between Some Types of Gravity Anomalies and. By Robert H. Miller. Abstract . . . 2097
Structure and Strength of the Earth. By Reginald Aldworth Daly. Review by Roland F. Beers . . . 1181
———. Review by William W. Rubey . . . 902
Student Awards, South Texas Geological Society. The Association Round Table . . . 1607
———, Houston Geological Society. The Association Round Table . . . 1606
———, West Texas Geological Society. The Association Round Table . . . 1188
Study of Sedimentation and Stratigraphy of Lower Mississippian in Western Michigan. By Lucille Hale . . . 713
Sub-Committee on Tertiary. By John G. Bartram. The Association Round Table . . . 2098
Submarine Topography off the California Coast: Canyons and Tectonic Interpretation. By Francis P. Shepard and K. O. Emery. Review by John L. Ferguson . . . 1940
Subsurface Mississippian Rocks of Kansas. By Wallace Lee. Review by Hugh McClellan . . . 1410
Subsurface Sections, Correlation of, with Outcrops of Ellenburger Formations of Texas. By Leo Hendricks. Abstract . . . 943
Subsurface Strata between Base of Osage Group and Top of Devonian Limestone in Illinois. By L. E. Workman and I. T. Sehwade. Abstract . . . 943
———, Devonian, in Western Kentucky. By Louise Barton Freeman . . . 668
Subsurface Study of Ellenburger Formation in West Texas. By Taylor Cole. Abstract . . . 934
——— of Jennings Dome, Acadia Parish, Louisiana. By C. B. Roach. Abstract 929
Summary of Faunal Studies of Navarro Group of Texas. By Lloyd William Stephenson . . . 637
Supplementary Membership List, September 1, 1941. The Association Round Table . . . 1821
Surface Geology, Rôle of, in Petroleum Exploration. By Edgar W. Owen Abstract . . . 936
Survey of Geology Students. By A. I. Levorsen. Research Notes . . . 910
Symposium. Temperature, Its Measurement and Control in Science and Industry. Review by Roger C. Wells . . . 1416
Szechuan, Cretaceous of, and North Shensi, China, Non-Marine Origin of Petroleum in. Geological Note by C. H. Pan . . . 2058

Taliaferro, N. L. Cretaceous of Santa Lucia Range. Abstract . . . 2095
———. The Franciscan Knoxville Problem. Abstract . . . 2095
Tansill Formation, West Texas and Southeastern New Mexico. By Ronald K. DeFord and George D. Riggs . . . 1713
Tarbell, Eleanor. Antrim-Ellsworth-Coldwater Shale Formations in Michigan 724
Tarbet, L. A. Geology of Del Valle Area. Abstract . . . 2096
Tasman, Cevat. Temperature Measurements in Three Wells in Southeastern Turkey. Geological Note . . . 1937
Tatum Salt Dome, Lamar County, Mississippi. Geological Note by Cecil L. Morgan . . . 424
Technique for Estimating Oil Reserves, Introduction to. By Park J. Jones. Abstract . . . 944
Technology, Petroleum, Annual Reviews of. By the Institute of Petroleum. Review by J. E. Brantly . . . 327
Technology and Petroleum Development, 1941. By A. I. M. E. Petroleum Division. Review by G. S. Dillé . . . 1950
Tectonic Interpretation and Canyons: Submarine Topography off the California Coast. By Francis P. Shepard and K. O. Emery. Review by John L. Ferguson . . . 1940
Tectonic Provinces, Major, of Southern Oklahoma and Their Relation to Oil and Gas Fields. By E. A. Paschal . . . 1

Teichert, Curt. Upper Paleozoic of Western Australia: Correlation and Paleogeography of . . . 371, 1809
Temblor Range, California, Crocker Flat Infolded Landslide and Coarse Clastics in. By Russell R. Simonson and Max L. Krueger. Abstract . . . 2097
———, California, Thrust Faulting and Coarse Clastics in. By F. S. Hudson and G. H. White . . . 1327
Temperature, Its Measurement and Control in Science and Industry. A symposium. Review by Roger C. Wells . . . 1416
Temperature Measurements in Three Wells in Southeastern Turkey. Geological note by Cevat Tasman . . . 1937
Tentative Correlation Chart of Gulf Coast. Geological Note by Chalmer J. Roy and Albert R. Glockzin . . . 742
Tertiary, Late, of the Nederlands East Indies, Small Foraminifera from. By L. W. LeRoy. Review by M. C. Israelsky . . . 761
——— of New Zealand, Divisions of. By H. J. Finlay and J. Marwick. Review by Hubert G. Schenck . . . 763
———, Sub-Committee on. By John G. Bartram. The Association Round Table . . . 2098
Tertiary and Upper Cretaceous in New Zealand, Divisions of. By H. J. Finlay and J. Marwick. Review by Burton Wallace Collins . . . 1813
Tertiary Foraminifera of Porto Rico. By J. J. Galloway and Caroline E. Heminway. Review by Alva C. Ellisor . . . 1810
Tertiary Geology of Australia. By F. A. Singleton. Review by Burton Wallace Collins . . . 1813
Tertiary Sediments, Gulf Coast, Comparative Study of Origin and Distribution of. By Carl B. Richardson. Abstract . . . 929
Texas, Clodine Field, Fort Bend County. Geological Note by Jack O. Colle . . . 2057
———, Coleman Pool Discovery, Archer County. Geological Note by Ward C. Bean . . . 428
———, Correlation of Subsurface Sections with Outcrops of Ellenburger Formation of. By Leo Hendricks. Abstract . . . 943
———, Davis Sand Lens, Hardin Field, Liberty County. By S. Russel Casey and Ralph B. Cantrell. Abstract . . . 930
———, East, Developments in, during 1940. By F. R. Denton and R. M. Trowbridge . . . 1081
———, Edna Gas Field, Jackson County. By M. M. Kornfeld and C. R. Steinberger . . . 104
———, Geology of Wasson Field, Gaines and Yoakum Counties. By W. T. Schneider. Abstract . . . 933
———, Hawkins Field, Wood County. Geological Note by H. J. McLellan . . . 898
———, Insoluble Residue Study Group, Midland. Geological Note by Taylor Cole . . . 318
———, La Rosa Field, Refugio County. By Barney Fisher . . . 300
———, North and West Central, New Developments in, 1940. By H. F. Smiley. Abstract . . . 940
———, North and West-Central, New Developments in, 1940. By North Texas Geological Society . . . 1064
———, North Cowden Field, Ector County. By Sam C. Giesey and Frank F. Fulk . . . 593
———, Oligocene Stratigraphy of East White Point Field, San Patricio and Nueces Counties. By Phil F. Martyn and Charles H. Sample . . . 1967
———. Abstract . . . 932
———, Page Field, Schleicher County. By Roscoe Simpson . . . 630
———, Relation of Initial Production to Ultimate Production of Wells Completed in Smithwick (Gray) Limestone, Breckenridge Field, Stephens County. Geological Note by David Donoghue . . . 1589
———, Silurian Production, Shipley Field, Ward County. Geological Note by C. D. Cordry and M. E. Upson . . . 425
———, South, Developments in, during 1940. By L. B. Herring . . . 1037
———, Abstract . . . 931
———, South Cotton Lake Field, Chambers County. By Joseph M. Wilson . . . 1898
———, Abstract . . . 931

———, Summary of Faunal Studies of Navarro Group of. By Lloyd William Stephenson 637
———, Upper, and Louisiana, Gulf Coast of, Review of Developments in 1940. By O. L. Brace. 1004
———, Walnut Bend Pool of Cooke County. By W. J. Hilseweck. Abstract. . 941
———, West, Geological Society. Possible Future Oil Provinces of West Texas. 1527
———, West, High-Pressure Yates Sand Gas Problem, Wasson Field, Yoakum County. By Alden S. Donnelly 1880
———, West, and New Mexico, Position of San Andres Group. By Frank E. Lewis 73
———, West, and Southeastern New Mexico, Developments in, during 1940. By Taylor Cole, Robert I. Dickey, and Edgar Kraus. 1044
———, West, and Southeastern New Mexico, Tansill Formation. By Ronald K. DeFord and George D. Riggs 1713
Texas and Louisiana, Résumé on Sedimentation in Gulf Coast Region of. By L. W. Storm. Abstract 936
Texas Coastal Plain between Brazos River and Rio Grande, Late Cenozoic Deposits of. By A. W. Weeks. Abstract 932
Texas Geological Society, North. New Developments in North and West-Central Texas, 1940 1064
Texas Gulf Coast, Basal Vicksburg Sand of. By A. N. Wilson. Abstract. . . 931
Texas Gulf Coastal Plain, Sedimentary Cycles in Eocene of. By H. B. Stenzel. Abstract 933
Theory of Ground-Water Motion. By M. King Hubbert. Review by L. K. Wenzel 1418
Thiel, G. A., and Poirier, O. A. Deposition of Free Oil by Sediments Settling in Sea Water 2170
Third Bradford Sand, Petroleum and Genesis of. By Paul D. Krynine. Review by Parke A. Dickey 1413
This Matter of Estimating Oil Reserves. Geological Note by Frederic H. Lahee. 164
Thrust Faulting and Coarse Clastics in Temblor Range, California, By F. S. Hudson and G. H. White. 1327
Thrusts, Heart Mountain and South Fork, Park County, Wyoming. By William G. Pierce 2021
Titusvilliidae, The; Paleozoic and Recent Branching Hexactinellida. By Kenneth E. Caster. Review by W. A. Ver Wiebe 2082
Toepelman, W. C. Microfaunas of Niobrara and Benton in Foothills of Northern Colorado. Abstract 940
Toler, Henry N. Review of Upper Cretaceous Deposits in Mississippi, by Lloyd William Stephenson and Watson Hiner Monroe 1601
Tomlinson, Charles W. Review of Geology, 1888–1938. Fiftieth Anniversary Volume of the Geological Society of America 2075
Tomlinson, C. W., Schenck, H. G., *et al.*, Hedberg, Hollis D., Eaton, J. E., and White, R. T. Stratigraphic Nomenclature. Discussion 2195
Topography, Submarine, off the California Coast: Canyons and Tectonic Interpretation. By Francis P. Shepard and K. O. Emery. Review by John L. Sullivan 1940
Torrance in Southern California, Miocene Fishes in Well Cores from. Geological Note by Lore David 319
Trace-Slip Faults. By R. H. Beckwith 2181
Traverse of Upper Des Moines and Lower Missouri Series from Jackson County, Missouri, to Appanoose County, Iowa. By L. M. Cline. 23
Trostel, Everett G., Dodge, John F., and Pyle, Howard C. Estimation by Volumetric Methods of Recoverable Oil and Gas from Sands 1302
Trowbridge, R. M., and Denton, F. R. Developments in East Texas during 1940 1081
———. Abstract 945
Tulsa Geological Society. Possible Future Oil Provinces of Northern Mid-Continent States 1508
Turkey, Southeastern, Temperature Measurements in Three Wells in. Geological Note by Cevat Tasman 1937
Twenhofel, W. H. Review of Sedimentary Petrography, by H. C. Milner . . 169
Twenhofel, W. H., and McKelvey, V. E. Sediments of Fresh-Water Lakes. . 826

Twenhofel, W. H., and Tyler, S. A. Methods of Study of Sediments. Review by Marcus A. Hanna 1420
Twenty-Seventh Annual Meeting, Denver, April 21–24, 1942. Announcement. The Association Round Table 1618, 1825, 1960, 2092, 2220
Twenty-Sixth Annual Business Meeting, Minutes, Rice Hotel, Houston, Texas, April 2–4, 1941. By Edgar W. Owen. The Association Round Table. . . 951
Twenty-Sixth Annual Meeting, Conferences. American Association of Petroleum Geologists. The Association Round Table 976
———, Houston, April 2–4, 1941. Announcement. The Association Round Table 179
———, Houston, April 2–4, 1941. By Alexander Deussen. Announcement. The Association Round Table 342, 535
———, Presidential Addresses at, American Association of Petroleum Geologists. The Association Round Table. 935
———, Remarks at Opening of. By George S. Buchanan 1201
———, Round Table Discussions at, American Association of Petroleum Geologists. The Association Round Table. 976
———, The American Association of Petroleum Geologists, Rice Hotel, Houston, Texas, April 2–4, 1941. The Association Round Table 918
Tygrett, H. V. Memorial of Baker Hoskins, Jr.. 2228
Tyler, S. A., and Twenhofel, W. H. Methods of Study of Sediments. Review by Marcus A. Hanna 1420
Types of Gravity Anomalies, Some, and Structure, Relationship Between. By Robert H. Miller. Abstract 2097

United States, Eastern, Possible Future Oil Provinces in. By Appalachian Geological Society 1563
———, 1940, Oil and Gas Field Development in. By National Oil Scouts and Landmen's Association. Review by Joseph L. Borden 1942
———, Southeastern, Possible Future Oil Provinces of. By Mississippi Geological Society 1575
United States and Canada, Possible Future Oil Provinces of. Foreword. By A. I. Levorsen 1433
University Oil Field, East Baton Rouge Parish, Louisiana, Oil and Gas Stratigraphic Reservoirs in. By Michel T. Halbouty. Abstract. 930
Upper Cretaceous Along West Border of San Joaquin Valley, Discussion of Part of. By A. S. Huey and J. W. Daly. Abstract 2096
Upper Cretaceous and Tertiary in New Zealand, Divisions of. By H. J. Finlay and J. Marwick. Review by Burton Wallace Collins 1813
Upper Cretaceous Deposits in Mississippi. By Lloyd William Stephenson and Watson Hiner Monroe. Review by Henry N. Toler 1601
Upper Cretaceous Stratigraphy of West Side of Sacramento Valley South of Willows, Glenn County, California. By James M. Kirby. Abstract. . . 2095
Upper Des Moines and Lower Missouri Series from Jackson County, Missouri, to Appanoose County, Iowa, Traverse of. By L. M. Cline 23
Upper Paleozoic of Western Australia: Correlation and Paleogeography. By Curt Teichert 371, 1809
Upper Texas and Louisiana, Gulf Coast of, Review of Developments in 1940. By O. L. Brace. 1004
Upson, M. E., and Cordry, C. D. Silurian Production, Shipley Field, Ward County, Texas. Geological Note 425

Vallat, Eugene H. Exploration Work in California during 1940. Abstract. . 946
Van Tuyl, F. M., and Parker, Ben H. Report of Committee on Migration and Accumulation of Petroleum. The Association Round Table 973
Velocity Variations, Seismic, in San Joaquin Valley, California. By Walter S. Olson 1343
Ver Wiebe, W. A. Report of Editor. The Association Round Table. . . . 961
———. Review of The Titusvilliidae; Paleozoic and Recent Branching Hexactinellida, by Kenneth E. Caster 2082
Vertebrate Record, Cretaceous, of California. By Chester Stock. Abstract. . 2094
Vicksburg Sand, Basal, of Texas Gulf Coast. By A. N. Wilson. Abstract. . . 931
Volumetric Methods, Estimation by, of Recoverable Oil and Gas from Sands. By John F. Dodge, Howard C. Pyle, and Everett G. Trostel. . . . 1302
Voskuil, Walter H. Oil in International Relations 353

Waldschmidt, W. A. Cementing Materials in Sandstones and Their Influence on Migration of Oil 1839
———. Progress Report on Microscopic Examination of Permian Crude Oils. Abstract 934
———. Results of Petrographic Studies of Sandstone Cores from Rocky Mountain Structures. Abstract 939
Walnut Bend Pool of Cooke County, Texas. By W. J. Hilseweck. Abstract. . 941
War and Petroleum. By Robert E. Wilson 1264
Ward County, Texas, Silurian Production, Shipley Field. Geological Note by C. D. Cordry and M. E. Upson 425
Warren County, Mississippi, Newman Salt Dome. Geological Note by Joseph Neely 424
Wasson Field, Gaines and Yoakum Counties, Texas, Geology of. By W. T. Schneider. Abstract 933
———, Yoakum County, West Texas, High-Pressure Yates Sand Gas Problem. By Alden S. Donnelly. 1880
Weaver, T. J., Ball, Max W., and Ball, Douglas S. Shoestring Sand Gas Fields of Michigan. Abstract. 942
Wedel, Arthur Albert. Memorial by Ira H. Cram 2230
Weeks, A. W. Late Cenozoic Deposits of Texas Coastal Plain between Brazos River and Rio Grande. Abstract. 932
Weeks, Warren B., and Purzer, Joseph. Developments in Southern Arkansas and Northern Louisiana during 1940 1024
———. Abstract 943
Well Logging by Radioactivity. By William L. Russell 1768
———. Discussion by William L. Russell 2211
———, Radioactivity, through Casing. By Lowell C. Beers. Abstract . . . 2098
Well Logs, Radioactivity, Their Use and Application in Fields of Petroleum Geology, Economic Geology, and Petroleum Engineering. By J. C. Barcklow. Abstract 938
Wells, Roger C. Review of Temperature, Its Measurement and Control in Science and Industry, a Symposium 1416
Wenzel, L. K. Review of The Theory of Ground-Water Motion, by M. King Hubbert. 1418
West-Central and North Texas, New Developments in, 1940. By North Texas Geological Society 1064
West Texas, High-Pressure Yates Sand Gas Problem, Wasson Field, Yoakum County. By Alden S. Donnelly 1880
———, Stratigraphic Trap of Slaughter Field of. By W. M. Osborn. Abstract. 934
———, Subsurface Study of Ellenburger Formation in. By Taylor Cole. Abstract 934
West Texas and New Mexico, Position of San Andres Group. By Frank E. Lewis 73
West Texas and Southeastern New Mexico, Developments in, during 1940. By Taylor Cole, Robert I. Dickey, and Edgar Kraus. 1044
———. Abstract 933
———, Tansill Formation. By Ronald K. DeFord and George D. Riggs . . 1713
West Texas Area, Abstracts of Papers on. The Association Round Table . . 933
West Texas Geological Society, Fall Field Trip, September 27–28. Field Trips 1838
———. Possible Future Oil Provinces of West Texas 1527
———, Spring Field Trip, May 10–11. Announcement. Field Trips 780
———, Student Merit Award. The Association Round Table 1188
West Virginia, Gay-Spencer-Richardson Oil and Gas Trend in. By E. T. Heck. Abstract 942
Western Australia, Upper Paleozoic of: Correlation and Paleogeography. By Curt Teichert 371, 1809
Western Canada, Possible Future Oil Provinces in. By Alberta Society of Petroleum Geologists 1447
Western Gulf Province, Analysis of Midway Fauna of. By Julia Gardner. . 644
Western Kentucky, Devonian Subsurface Strata in. By Louise Barton Freeman. 668
———, Post-Appalachian Faulting in. By Roger Rhoades and Alvin J. Mistler 2046
Where Should Young Graduates in Petroleum Geology Acquire Field Experience? Discussion by Frederic H. Lahee 167

———? Discussion by Ralph B. Ross 1180
White, G. H., and Hudson, F. S. Thrust Faulting and Coarse Clastics in Temblor Range, California 1327
White, R. T., Schenck, H. G., *et al.*, Hedberg, Hollis D., Tomlinson, C. W., and Eaton, J. E. Stratigraphic Nomenclature. Discussion 2195
White Point Field, East, San Patricio and Nueces Counties, Texas, Oligocene Stratigraphy of. By Phil F. Martyn and Charles H. Sample 1967
———. Abstract 932
Whitehead, W. L., and Goodman, Clark. Progress Report on Radioactivity of Petroleum and Natural Gas. The Association Round Table 975
Why Crudes Differ in Value. By H. D. Wilde 1167
———. Abstract 937
Wichita and Arbuckle Mountains of Oklahoma, Simpson Group of. By Charles E. Decker 650
Wichita Mountains, Oklahoma, Pre-Cambrian Zeolite-Opal Sediments in. By C. A. Merritt and W. E. Ham 287
Wilcox Faunal Units of Louisiana, Correlation of. By J. O. Barry. Abstract . . 941
Wildcat Drilling in 1940. By Frederic H. Lahee 997, 1938
———. Abstract 938
Wilde, H. D. Why Crudes Differ in Value 1167
———. Abstract 937
Willis, Robin. Northwest Extension of Inglewood Field. Abstract 2097
———. Some Drilling-Time Logs and Their Uses. Abstract 2097
Willows, Cretaceous—West Side Sacramento Valley North of. By Philip W. Reinhart. Abstract 2095
———, Glenn County, California, Upper Cretaceous Stratigraphy of West Side of Sacramento Valley South of. By James M. Kirby. Abstract 2095
Wilson, A. N. Basal Vicksburg Sand of Texas Gulf Coast. Abstract . . . 931
Wilson, Joseph M. South Cotton Lake Field, Chambers County, Texas . . 1898
———. Abstract 931
Wilson, Robert E. Petroleum and the War 1264
Wind River Mountains, Wyoming, Geology of. By E. B. Branson and C. C. Branson 120
Wolf, Albert G., and Hanna, Marcus A. Gold, Silver, and Other Elements in Salt-Dome Cap Rocks. Geological Note 750
Wood County, Texas, Hawkins Field. Geological Note by H. J. McLellan . . 898
Woodward, A. F. Recently Discovered Middle Miocene Production in Inglewood Oil Field. Abstract 947
Woolnough, Walter George, Honorary Member. By J. T. Richards. The Association Round Table 1954
Workman, L. E., and Sehwade I. T. Subsurface Strata between Base of Osage Group and Top of Devonian Limestone in Illinois. Abstract 943
Wrather, W. E. Memorial of Robert Thomas Hill 2221
Wyoming, Exploration for Evaporite Salts in Green River Basin. Geological Note by R. G. Greene 1799
———, Geology of Freezeout Mountain-Bald Mountain Area, Carbon County. By Milan D. Maravich 883
———, Geology of Southern Part of La Barge Region, Lincoln County. By A. J. Bertagnolli, Jr. 1729
———, Geology of Wind River Mountains. By E. B. Branson and C. C. Branson 120
———, Heart Mountain and South Fork Thrusts, Park County. By William G. Pierce 2021
———, Permian Correlation Meeting, Centennial, September 2, 1940. Geological Note by Ronald K. DeFord 429

Yabe, Hisakatsu. Paleozoic Formations of the Japanese Islands. Review by Hubert G. Schenck 767
Yates Sand Gas Problem, High-Pressure, Wasson Field, Yoakum County, West Texas. By Alden S. Donnelly 1880
Yoakum County, West Texas, High-Pressure Yates Sand Gas Problem, Wasson Field. By Alden S. Donnelly 1880

Young Graduates in Petroleum Geology, Where Should They Acquire Field Experience? Discussion by Frederic H. Lahee 167
———? Discussion by Ralph B. Ross 1180

Zavoico, Basil B. Foreign Developments during 1939 and 1940. Abstract. . 937
Zeolite-Opal Sediments, Pre-Cambrian, in Wichita Mountains, Oklahoma. By C. A. Merritt and W. E. Ham 287

BULLETIN
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WALTER A. VER WIEBE, *Editor*

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PART I

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CONTENTS OF VOLUME 25 (1941)

PART I

NUMBER 1 (JANUARY)

Major Tectonic Provinces of Southern Oklahoma and Their Relation to Oil and Gas Fields, *E. A. Paschal* 1

Traverse of Upper Des Moines and Lower Missouri Series from Jackson County, Missouri, to Appanoose County, Iowa, *L. M. Cline* 23

Position of San Andres Group, West Texas and New Mexico, *Frank E. Lewis* 73

Edna Gas Field, Jackson County, Texas, *M. M. Kornfeld and C. R. Steinberger* 104

Geology of Wind River Mountains, Wyoming, *E. B. Branson and C. C. Branson* 120

New Source for Sodium Sulphate in New Mexico, *Walter B. Lang* . 152

GEOLOGICAL NOTES

Devonian and Mississippian Inliers of Southwestern Pennsylvania, *Wilson M. Laird* 161

This Matter of Estimating Oil Reserves, *Frederic H. Lahee* . 164

DISCUSSION

Where Should Young Graduates in Petroleum Geology Acquire Field Experience?, *Frederic H. Lahee* 167

REVIEWS AND NEW PUBLICATIONS 168

RESEARCH NOTES 177

THE ASSOCIATION ROUND TABLE 178

MEMORIAL

Howard Walter Handley, *Verner Jones* 184

AT HOME AND ABROAD 185

NUMBER 2 (FEBRUARY)

Miocene of Caliente Range and Environs, California, *J. E. Eaton, U. S. Grant, and H. B. Allen* 193

Micropaleontology and Stratigraphy of a Deep Well at Niceville, Okaloosa County, Florida, *R. Hendee Smith* 263

Pre-Cambrian Zeolite-Opal Sediments in Wichita Mountains, Oklahoma, *C. A. Merritt and W. E. Ham* 287

La Rosa Field, Refugio County, Texas, *Barney Fisher* 300

GEOLOGICAL NOTES

Midland, Texas, Insoluble Residue Study Group, *Taylor Cole* . 318

Miocene Fishes in Well Cores from Torrance in Southern California, *Lore David* 319

Age of Abyssal Desposits of East Indian Archipelago, *Carl C. Branson* 320

Barataria Field, Jefferson Parish, Louisiana, *Al Ferrando and H. T. Richardson* 322

DISCUSSION

Future of Field Geology, *R. Dana Russell* 324

REVIEWS AND NEW PUBLICATIONS 327
RESEARCH NOTES 337
THE ASSOCIATION ROUND TABLE 338
MEMORIAL
Thomas Mann Prettyman, *C. L. Renaud* 346
Thurman H. Myers, *M. G. Gulley* 347
AT HOME AND ABROAD 349

NUMBER 3 (MARCH)

Oil in International Relations, *Walter H. Voskuil* 353
Upper Paleozoic of Western Australia: Correlation and Paleogeography, *Curt Teichert* 371
Some Problems of Appalachian Structure, *R. E. Sherrill* 416
GEOLOGICAL NOTES
Newman Salt Dome, Warren County, Mississippi, *Joseph Neely* 424
Tatum Salt Dome, Lamar County, Mississippi, *Cecil L. Morgan* 424
Silurian Production, Shipley Field, Ward County, Texas, *C. D. Cordry and M. E. Upson* 425
Coleman Pool Discovery, Archer County, Texas, *Ward C. Bean* 428
Permian Correlation Meeting, Centennial, Wyoming, September 2, 1940, *Ronald K. DeFord* 429
REVIEWS AND NEW PUBLICATIONS 440
THE ASSOCIATION ROUND TABLE
Financial Statement, 1940 448
Association Membership List, March 6, 1941 457
MEMORIAL
Marius Robinson Campbell, *G. B. Richardson* 546
AT HOME AND ABROAD 551

NUMBER 4 (APRIL)

Correlation of Crude Oils with Special Reference to Crude Oil of Gulf Coast, *Donald C. Barton* 561
North Cowden Field, Ector County, Texas, *Sam C. Giesey and Frank F. Fulk* 593
Page Field, Schleicher County, Texas, *Roscoe Simpson* 630
Summary of Faunal Studies of Navarro Group of Texas, *Lloyd William Stephenson* 637
Analysis of Midway Fauna of Western Gulf Province, *Julia Gardner*. 644
Simpson Group of Arbuckle and Wichita Mountains of Oklahoma, *Charles E. Decker* 650
Devonian Subsurface Strata in Western Kentucky, *Louise Barton Freeman* 668
Study of Sedimentation and Stratigraphy of Lower Mississippian in Western Michigan, *Lucille Hale* 713
Antrim-Ellsworth-Coldwater Shale Formations in Michigan, *Eleanor Tarbell*. 724

GEOLOGICAL NOTES
Fossiliferous Localities of Midway Group in Louisiana, *Rufus J. LeBlanc and John O. Barry* 734
Midway Microfauna of Northwestern Louisiana, *Grover Murray, Jr.* 738
Tentative Correlation Chart of Gulf Coast, *Chalmer J. Roy and Albert R. Glockzin* 742
Olla Field, La Salle Parish, Louisiana, *S. A. Packard and H. R. Kamb* 747
Gold, Silver, and Other Elements in Salt-Dome Cap Rocks, *Marcus A. Hanna and Albert G. Wolf* 750
Formation Samples from Gun Perforators, *J. T. Richards* . . 752
REVIEWS AND NEW PUBLICATIONS. 760
THE ASSOCIATION ROUND TABLE 772
AT HOME AND ABROAD 778

NUMBER 5 (MAY)

Central Basin of Appalachian Geosyncline, *Robert C. Lafferty* . . . 781
Sediments of Fresh-Water Lakes, *W. H. Twenhofel and V. E. McKelvey* 826
Laboratory and Field Observations of Effect of Acidizing Oil Reservoirs Composed of Sands, *P. E. Fitzgerald, J. R. James, and Ray L. Austin* 850
Cross Section of Chester of Illinois Basin, *P. L. Dana and E. H. Scobey* . 871
Geology of Freezeout Mountain-Bald Mountain Area, Carbon County, Wyoming, *Milan D. Maravich* 883
GEOLOGICAL NOTES
Hawkins Field, Wood County, Texas, *H. J. McLellan* . . . 898
Applied Sedimentology, *Henry Carter Rea* 899
REVIEWS AND NEW PUBLICATIONS. 902
RESEARCH NOTES 910
THE ASSOCIATION ROUND TABLE
Twenty-Sixth Annual Meeting, Houston, April 2–4, 1941 . . 918
Minutes, Twenty-Sixth Annual Meeting, *Edgar W. Owen* . . 951
AT HOME AND ABROAD 991

NUMBER 6 (JUNE)

RECENT DEVELOPMENTS
Wildcat Drilling in 1940, *Frederic H. Lahee* 997
Review of Developments in 1940, Gulf Coast of Upper Texas and Louisiana, *O. L. Brace* 1004
Developments in Mississippi in 1940, *Urban B. Hughes* 1016
Developments in Southern Arkansas and Northern Louisiana during 1940, *Joseph Purzer and Warren B. Weeks* 1024
Developments in South Texas during 1940, *L. B. Herring* 1037
Developments in West Texas and Southeastern New Mexico during 1940, *Taylor Cole, Robert I. Dickey, and Edgar Kraus* . . . 1044

New Developments in North and West-Central Texas, 1940, *North Texas Geological Society* 1064
Developments in East Texas during 1940, *F. R. Denton and R. M. Trowbridge* 1081
Developments in Oklahoma during 1940, *E. F. Shea* 1090
Developments in North Mid-Continent in 1940, *Edward A. Koester* . 1103
Development in Eastern Interior Basin 1940, *Alfred H. Bell* . . . 1114
Oil and Gas Developments in Michigan in 1940, *R. P. Grant* . . . 1125
Developments in Appalachian Area during 1940, *Appalachian Geological Society* 1135
Developments in Rocky Mountain District in 1940, *C. E. Dobbin* . 1149
California Exploration and Development in 1940, *Eugene H. Vallat* . 1159
Why Crudes Differ in Value, *H. D. Wilde* 1167
GEOLOGICAL NOTES
Significance of Initial Daily Production of Wells in Burbank and South Burbank Oil Fields, Oklahoma, *N. Wood Bass* . . 1175
DISCUSSION
Where Should Young Graduates in Petroleum Geology Acquire Field Experience?, *Ralph B. Ross* 1180
REVIEWS AND NEW PUBLICATIONS. 1181
THE ASSOCIATION ROUND TABLE 1186
AT HOME AND ABROAD 1192

ERRATA

Page 382, line 20. Carbonaceous should be *Bituminous*.

Page 385, Figs. 3 and 4. Explanations are interchanged.

Page 390, Fig. 5. Wooramel sandstone has been erroneously omitted from Gascoyne and Minilya columns. See stratigraphic description of Wooramel on page 379.

Page 997, Abstract, 2d line. 10,253,948 should be *10,144,870*.
3d line. 3,375 should be *3,339*.
4th line. 4,284 should be *4,209*.

Page 998, Fig. 1. In Alabama, figure in parenthesis under the line, (151,493) should be (*42,415*). In lower right corner of cut, figure in parenthesis under the line, (8,842,418) should be (*8,733,340*).

Fig. 2. In Alabama, figure in parenthesis under the line, (151,493) should be (*42,415*). In upper right part of cut, figure in parenthesis under the line, (5,360,351) should be (*5,251,273*). Figure for dry feet, 5.83, should be *5.71*.

Page 999, 3d new paragraph, 2d line. 10,253,948 should be *10,144,870*.
5th line. 8,842,418 should be *8,733,340*.
6th line. 13.77 should be *13.91*.
8th line. 3,375 should be *3,339*.
Fourth new paragraph, 1st line. 6,279,857 should be *6,170,779*.
4th line. 5,360,351 should be *5,251,273*.
5th line. 14.64 should be *14.90*.

Page 1000, Table I. In Alabama line, 151,493 should be *42,415*. In Totals line, 8,842,418 should be *8,733,340;* and 10,253,948 should be *10,144,870*.

Page 1001, Table II. In 1940 line, 14.6 should be *14.9;* 5,360,351 should be *5,251,273;* 85.4 should be *85.1;* 4,284 should be *4,209;* 5.83 should be *5.71*.

Page 1002, 1st line. 4,284 should be *4,209*.

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CONTENTS OF VOLUME 25 (1941)

PART II

NUMBER 7 (JULY)

Remarks at Opening of Twenty-Sixth Annual Meeting, *George S. Buchanan* 1201
Petroleum Geologists in the National Defense Program, *L. C. Snider* . 1203
Micropaleontology—Past and Future, *Carey Croneis* 1208
The Future of Geophysics, *W. T. Born* 1256
Petroleum and the War, *Robert E. Wilson* 1264
Fifth Dimension in the Oil Industry, *J. Edgar Pew* 1283
Natural Gas with Regard to Its Place in National Defense, *N. C. McGowen* 1291
The Petroleum Geologist and the Securities and Exchange Commission, *Sumner T. Pike* 1297
Estimation by Volumetric Methods of Recoverable Oil and Gas from Sands, *John F. Dodge, Howard C. Pyle, and Everett G. Trostel* . 1302
Thrust Faulting and Coarse Clastics in Temblor Range, California, *F. S. Hudson and G. H. White* 1327
Seismic Velocity Variations in San Joaquin Valley, California, *Walter S. Olson* 1343
Geology of Eola Oil Field, Avoyelles Parish, Louisiana, *Fred W. Bates* . 1363
Classification of the Artinskian Series in Russia, *G. Marshall Kay* . 1396
GEOLOGICAL NOTES
Effective Porosity of Gas Fields in Jackson County, Missouri, *Glenn G. Bartle* 1405
REVIEWS AND NEW PUBLICATIONS 1410
THE ASSOCIATION ROUND TABLE 1425
AT HOME AND ABROAD 1430

NUMBER 8 (AUGUST)

POSSIBLE FUTURE OIL PROVINCES OF THE UNITED STATES AND CANADA
Foreword, *A. I. Levorsen* 1433
Alaska, *Philip S. Smith* 1440
Western Canada, *Alberta Society of Petroleum Geologists* 1447
Pacific Coast States, *Pacific Section, American Association of Petroleum Geologists* 1457
Rocky Mountain Region, *Rocky Mountain Association of Petroleum Geologists* 1469
Northern Mid-Continent States, *Tulsa Geological Society* 1508
West Texas, *West Texas Geological Society* 1527
Eastern Canada, *Geological Survey of Canada, Quebec Bureau of Mines, and Newfoundland Geological Survey* 1539
Eastern United States, *Appalachian Geological Society* 1563
Southeastern United States, *Mississippi Geological Society* . . . 1575

GEOLOGICAL NOTES
Oil-Field Models of Shreveport Geological Society, *C. E. Dobbin* 1587
Relation of Initial Production to Ultimate Production of Wells Completed in Smithwick (Gray) Limestone, Breckenridge Field, Stephens County, Texas, *David Donoghue* 1589
Memorial Shale of Pennsylvanian Age, in Oklahoma, *Robert H. Dott* 1591
RESEARCH NOTES
Ellenburger Structure Map of Central Texas, *A. I. Levorsen* . 1600
REVIEWS AND NEW PUBLICATIONS. 1601
THE ASSOCIATION ROUND TABLE 1605
MEMORIAL
Jesse Elmore Simmons, *E. W. Kimball* 1610
Roger W. Sawyer, *Malcolm C. Oakes* 1610
AT HOME AND ABROAD 1613

NUMBER 9 (SEPTEMBER)

Regional Stratigraphy of Mid-Continent, *Robert H. Dott* 1619
Exercise on Amount of Source Bed Required to Furnish Oklahoma City Oil Pool, *Roy L. Ginter* 1706
Tansill Formation, West Texas and Southeastern New Mexico, *Ronald K. DeFord and George D. Riggs* 1713
Geology of Southern Part of La Barge Region, Lincoln County, Wyoming, *A. J. Bertagnolli, Jr.* 1729
Correlation of Cross' La Plata Sandstone, Southwestern Colorado, *Marcus I. Goldman and Arthur C. Spencer*. 1745
Well Logging by Radioactivity, *William L. Russell* 1768
Pre-Cretaceous Sediments in Cordillera Oriental of Colombia, *Parke A. Dickey* 1789
GEOLOGICAL NOTES
Photogeology, *Henry Carter Rea* 1796
Exploration for Evaporite Salts in Green River Basin, Wyoming, *R. G. Greene* 1799
RESEARCH NOTES
Relationship of Crude Oils and Stratigraphy in Parts of Oklahoma and Kansas, *L. M. Neumann et al.* 1801
REVIEWS AND NEW PUBLICATIONS. 1810
THE ASSOCIATION ROUND TABLE 1820
MEMORIAL
George Martin Hall, *Joseph T. Singewald, Jr.* 1828
Charles Theodore Casebeer, *E. A. Paschal* 1831
AT HOME AND ABROAD 1833

NUMBER 10 (OCTOBER)

Cementing Materials in Sandstones and Their Influence on Migration of Oil, *W. A. Waldschmidt* 1839
High-Pressure Yates Sand Gas Problem, Wasson Field, Yoakum County, West Texas, *Alden S. Donnelly* 1880

South Cotton Lake Field, Chambers County, Texas, *Joseph M. Wilson* 1898
Relation of Organic Matter to Color of Sedimentary Rocks, *H. Whitman Patnode* 1921
GEOLOGICAL NOTES
Migration of Oil from Arbuckle Limestone into Chattanooga Shale in Chetopa Oil Pool, Labette County, Kansas, *G. E. Abernathy* 1934
Temperature Measurements in Three Wells in Southeastern Turkey, *Cevat Tasman* 1937
Wildcat Drilling in 1940—Correction, *Frederic H. Lahee* . . 1938
REVIEWS AND NEW PUBLICATIONS 1940
THE ASSOCIATION ROUND TABLE 1954
MEMORIAL
Henry Hart Pratley, *Fred Pratley* 1962
Eugene Law Ickes, *Max L. Krueger* 1962
AT HOME AND ABROAD 1964

NUMBER 11 (NOVEMBER)

Oligocene Stratigraphy of East White Point Field, San Patricio and Nueces Counties, Texas, *Phil F. Martyn and Charles H. Sample* . 1967
Sedimentation and Oil Accumulation on Gulf Coast, *Doris Malkin and Dorothy A. Jung* 2010
Heart Mountain and South Fork Thrusts, Park County, Wyoming, *William G. Pierce* 2021
Post-Appalachian Faulting in Western Kentucky, *Roger Rhoades and Alvin J. Mistler* 2046
GEOLOGICAL NOTES
Clodine Field, Fort Bend County, Texas, *Jack O. Colle* . . 2057
Non-Marine Origin of Petroleum in North Shensi, and the Cretaceous of Szechuan, *C. H. Pan* 2058
Improved Method of Handling Microfilm Copy, *H. T. U. Smith* 2068
DISCUSSION
Graywackes and the Petrology of Bradford Oil Field, Pennsylvania, *Paul D. Krynine* 2071
REVIEWS AND NEW PUBLICATIONS 2075
RESEARCH NOTES
The Origin of Oil, *A. I. Levorsen* 2086
THE ASSOCIATION ROUND TABLE 2087
MEMORIAL
Samuel W. Riter, *D. G. Emrick* 2100
Otto Leatherock, *J. B. Hoover* 2101
AT HOME AND ABROAD 2102

NUMBER 12 (DECEMBER)

Mississippian Formations of Sacramento Mountains, New Mexico, *L. R. Laudon and A. L. Bowsher* 2107
Experiments with Lights, Shadows, and Contours, and Resulting Shadowgraphic Contour Maps, *Robert F. Imbt* 2161

Deposition of Free Oil by Sediments Settling in Sea Water, *O. A. Poirier and George A. Thiel* 2170
Trace-Slip Faults, *R. H. Beckwith* 2181
GEOLOGICAL NOTES
Apache Pool, Caddo County, Oklahoma, *H. H. Arnold, Jr.* . 2194
DISCUSSION
Stratigraphic Nomenclature, *H. G. Schenck et al., Hollis D. Hedberg, C. W. Tomlinson, J. E. Eaton, and R. T. White* . 2195
Well Logging by Radioactivity, *William L. Russell* 2211
REVIEWS AND NEW PUBLICATIONS 2212
THE ASSOCIATION ROUND TABLE 2216
MEMORIAL
Robert Thomas Hill, *W. E. Wrather* 2221
Baker Hoskins, Jr., *H. V. Tygrett* 2228
Arthur Albert Wedel, *Ira H. Cram* 2230
AT HOME AND ABROAD 2232
INDEX OF VOLUME 25 (1941) 2235

ERRATA

Page 1230. 2d name in 2d column of names should be Professor Charles Schuchert.
Pages 1382 and 1385. Cut lines of Figures 8 and 10 are interchanged.
Page 1413. In title of review, Petroleum should be *Petrology.*
Page 1540, Fig. 3. Williams Sound should be Williams *Island.*
Page 1541, paragraph 2, line 7. Delete question mark.
Page 1552, Fig. 12, last column. After Windsor series, non-marine should be *marine and continental.*
Page 1786, Fig. 4. Near top of cut, Ruster anhydrite should be *Rustler* anhydrite. In cut line, Copper pool should be *Cooper* pool.

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Meetings: First and third Wednesdays of each month ,from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

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Meetings: Second and fourth Wednesdays, each month, from October to May, inclusive, at 8:00 P.M.

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Meetings: Third Friday of each month alternately in San Antonio and Corpus Christi. Luncheon every Monday noon at Milam Cafeteria, San Antonio, and at Plaza Hotel, Corpus Christi.

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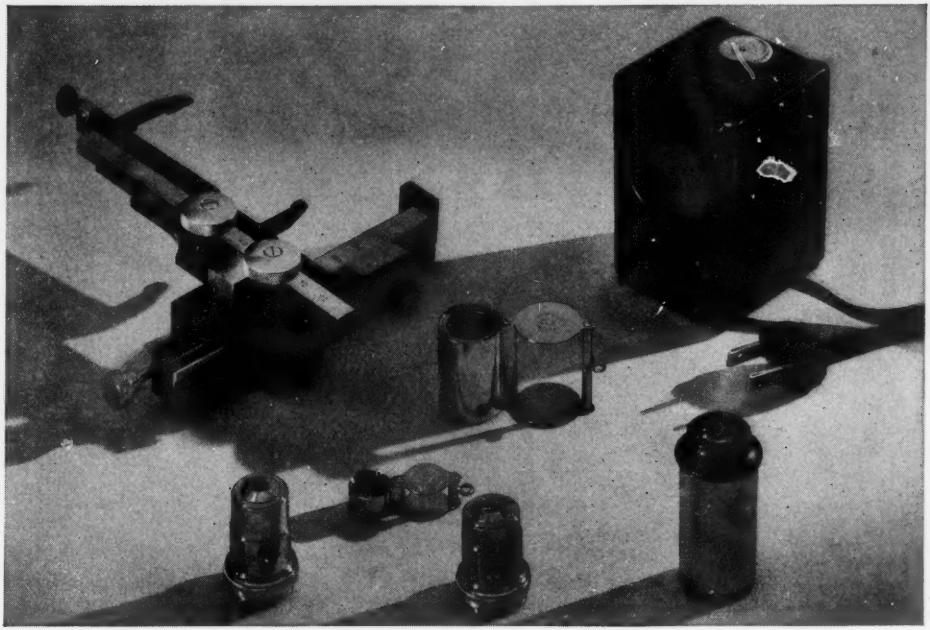

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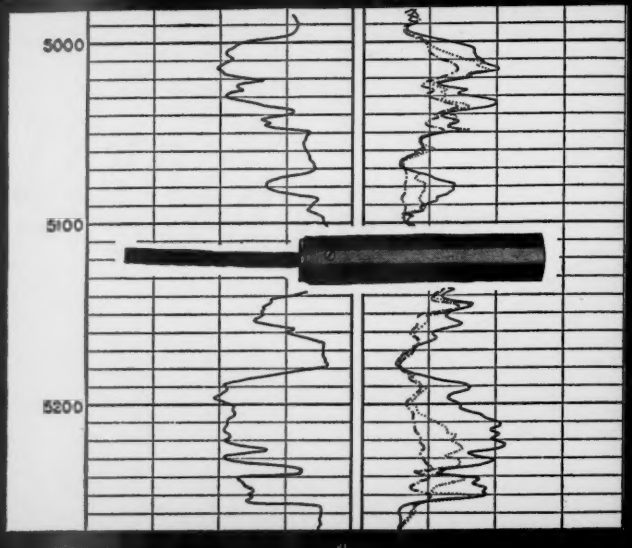

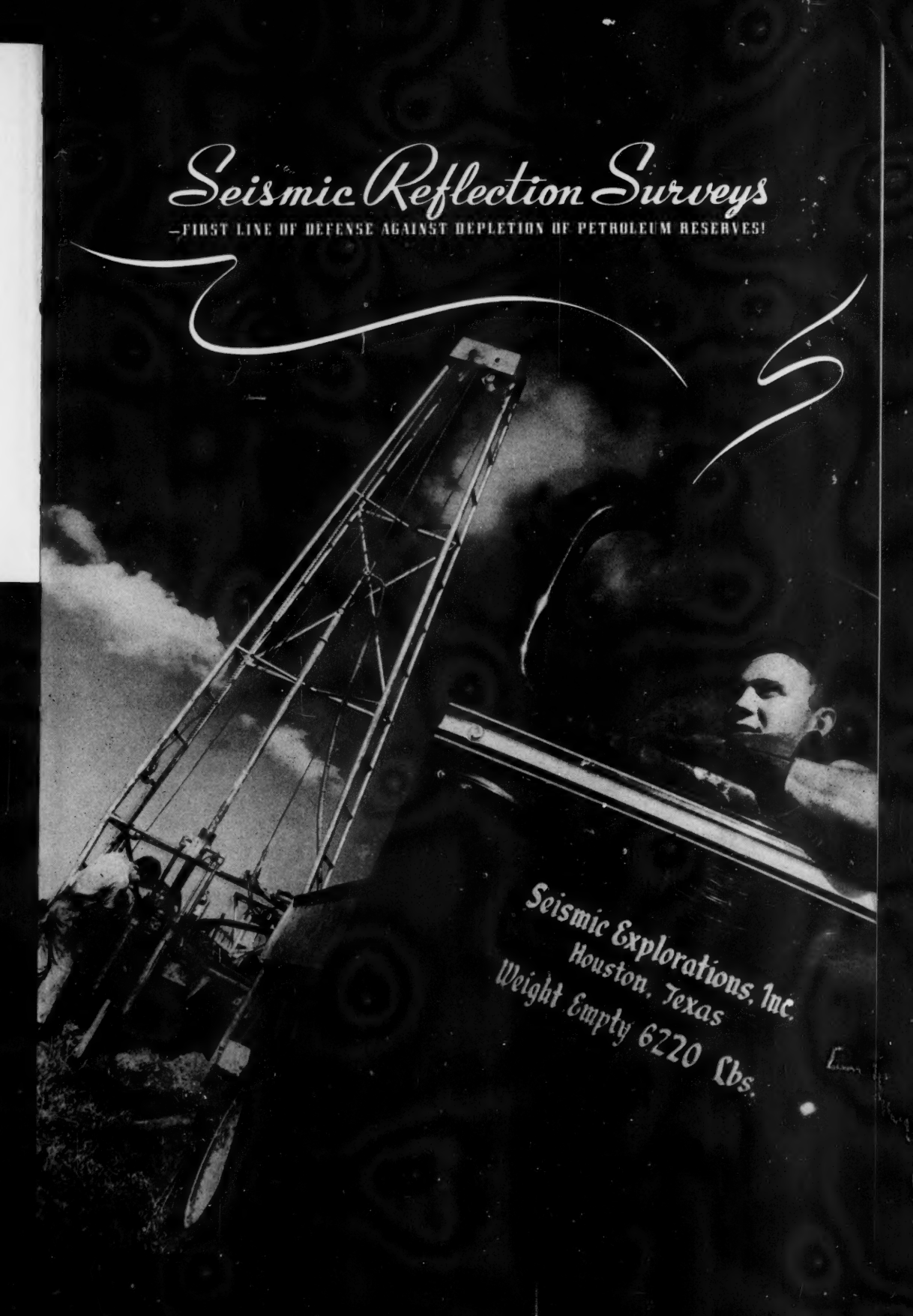
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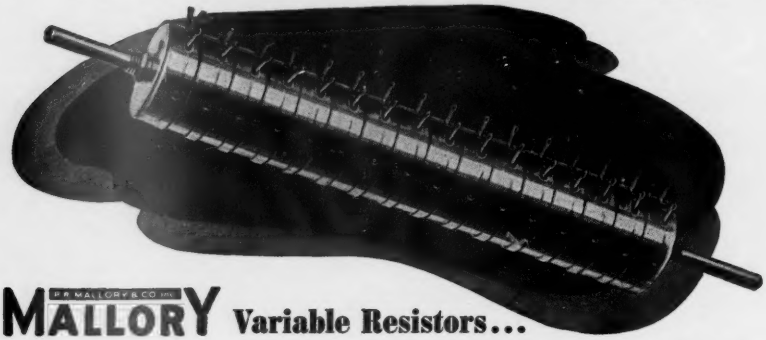

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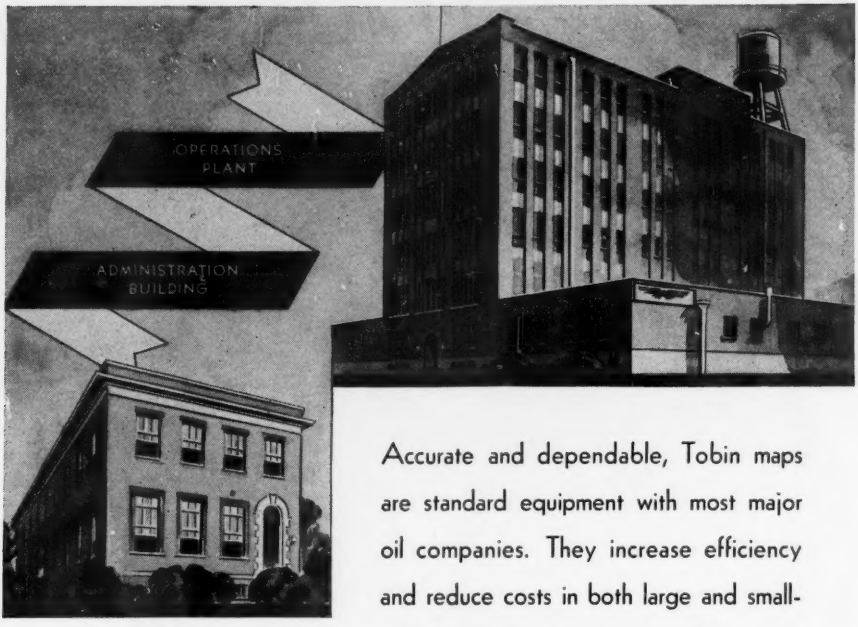

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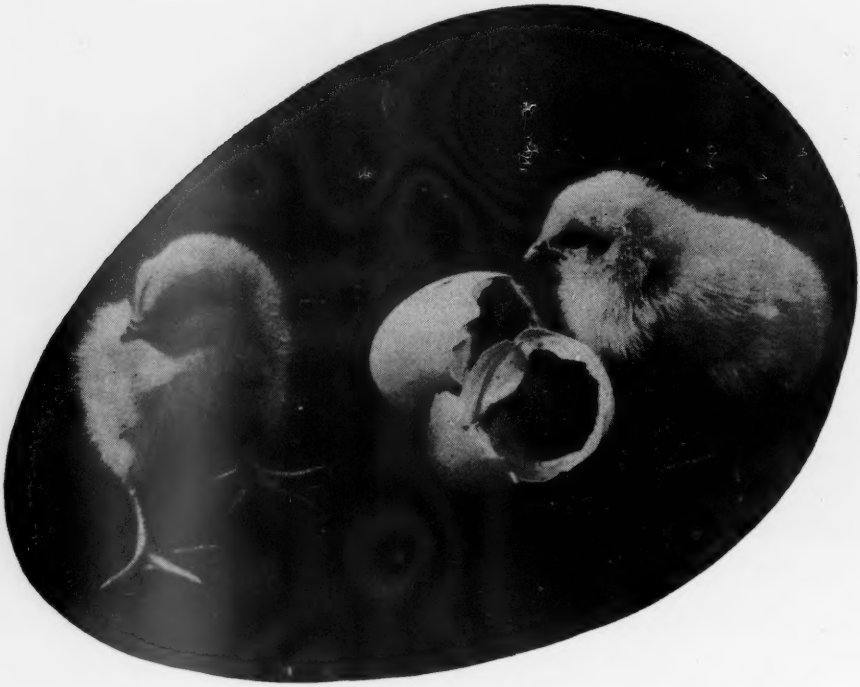

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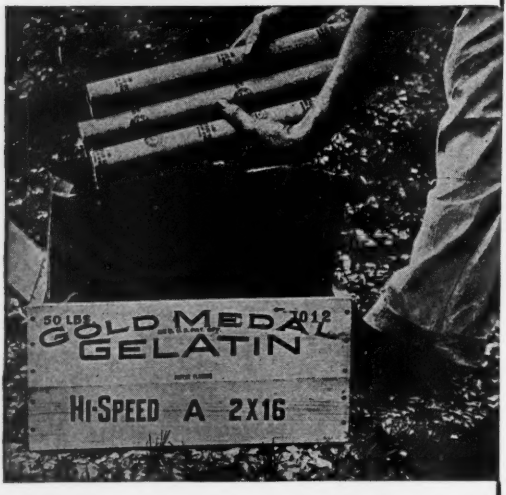

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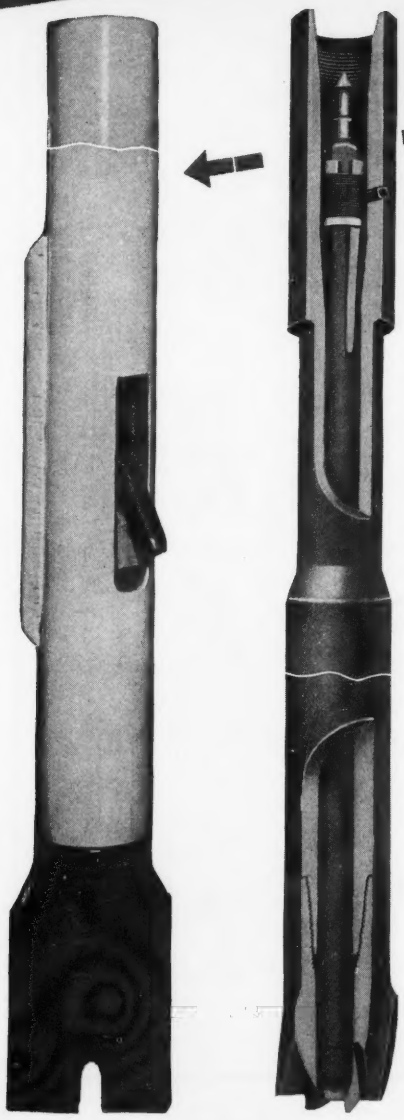

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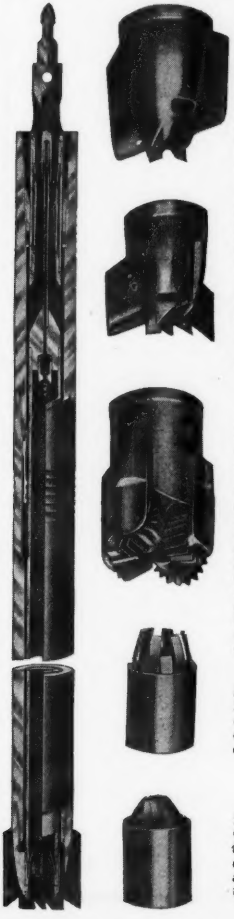

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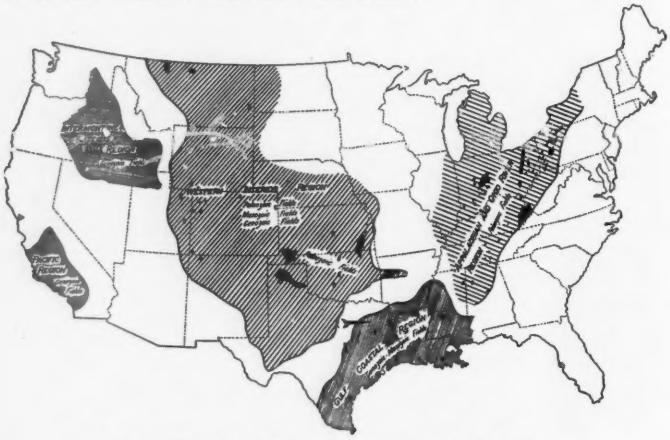

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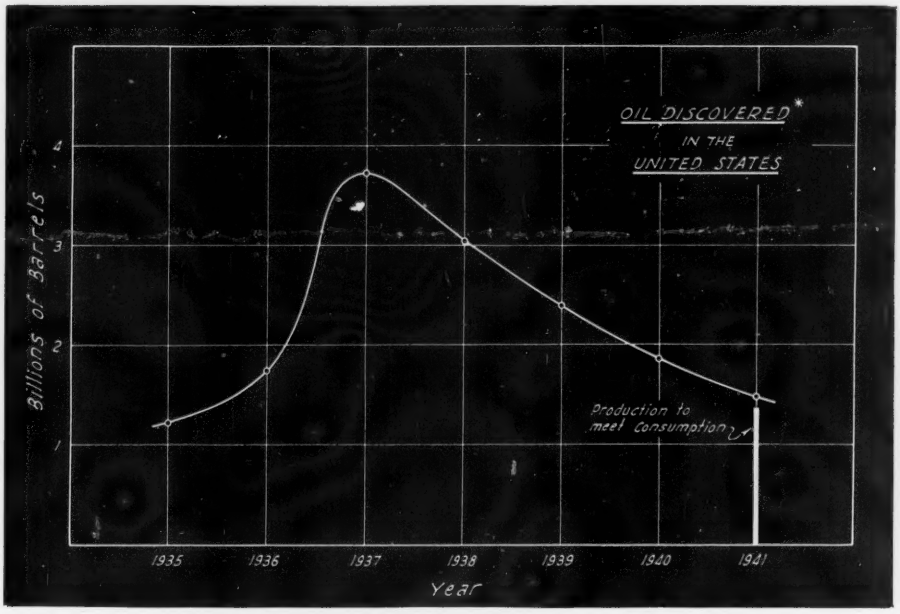

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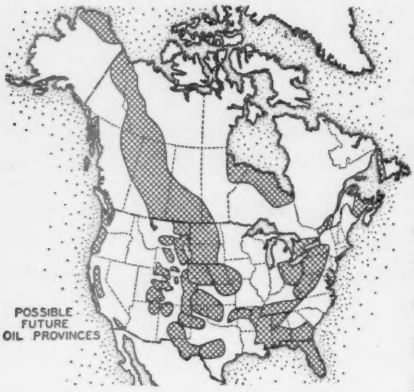

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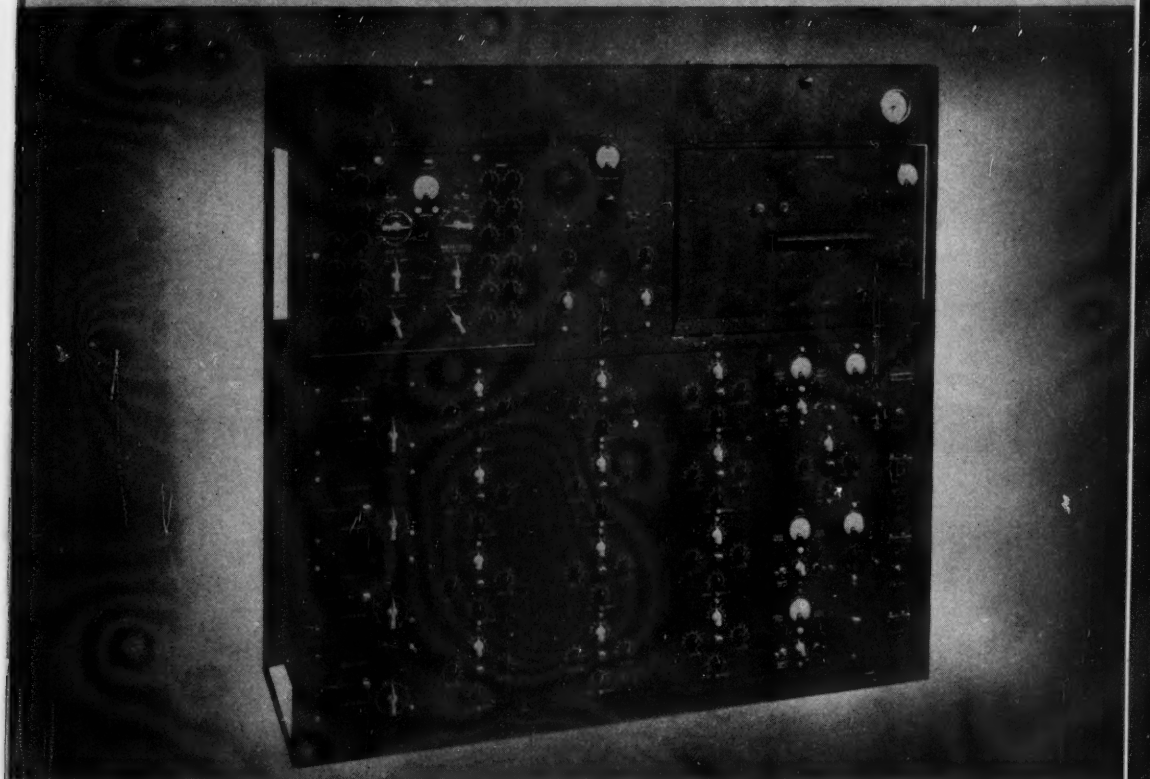

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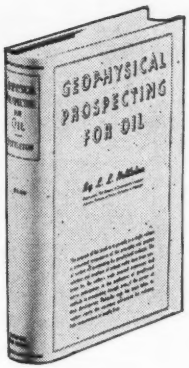

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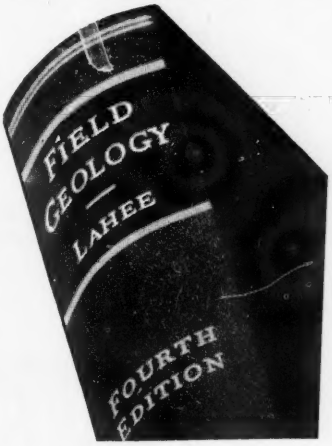

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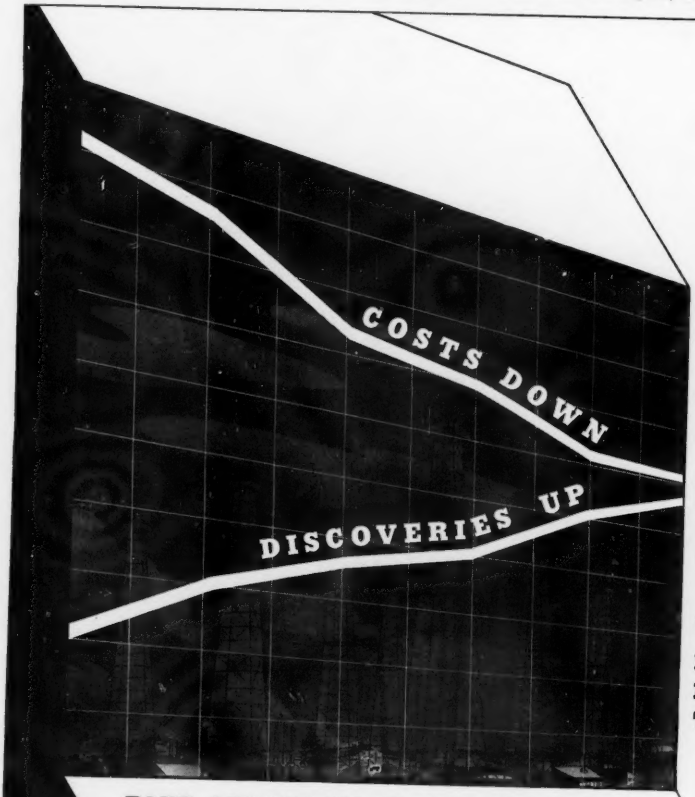

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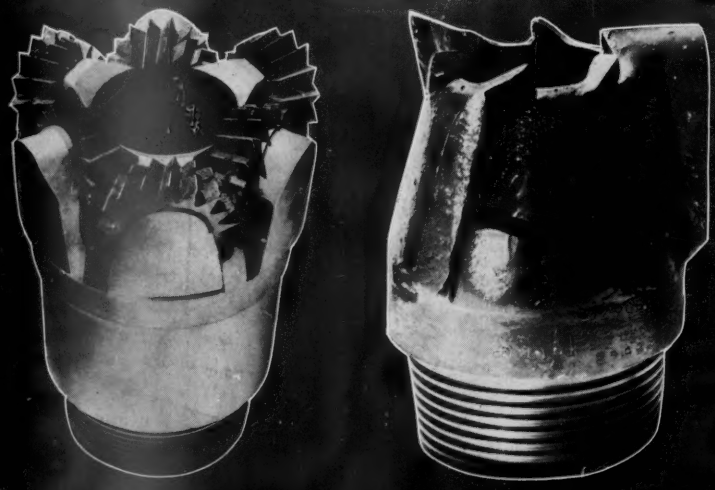

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